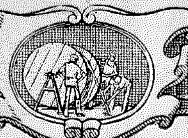
Mr. C. P. Smith



ELECTRICAL COMMUNICATION

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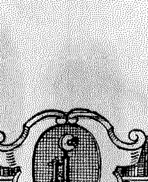

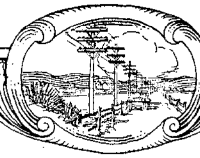

ELECTRICAL COMMUNICATION

A Journal of Progress in the Telephone, Telegraph and Radio Art

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CONTENTS

A RURAL ROTARY AUTOMATIC TELEPHONE SYSTEM INSTALLED AT HERRLIBERG 3
By W. Hatton

CONTROL OF RELEASE TIME OF RELAYS IN AUTOMATIC TELEPHONE SYSTEMS 9
By R. St. G. Terry

INTERCALL SELECTOR SYSTEM ON THE SWEDISH STATE RAILWAY 16
By Ivar Billing

SALESMANSHIP IN TELEPHONE DEVELOPMENT 25
By R. M. Reinoehl

THE MODERN PLANT OF THE NIPPON ELECTRIC COMPANY, LIMITED, AT TOKYO 28
By A. G. Jillard

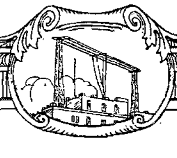
PHASE RELATIONS IN UNBALANCED TWO-WAY TELEPHONE REPEATERS 34
By L. T. Hinton, A. R. A. Rendall and C. S. White

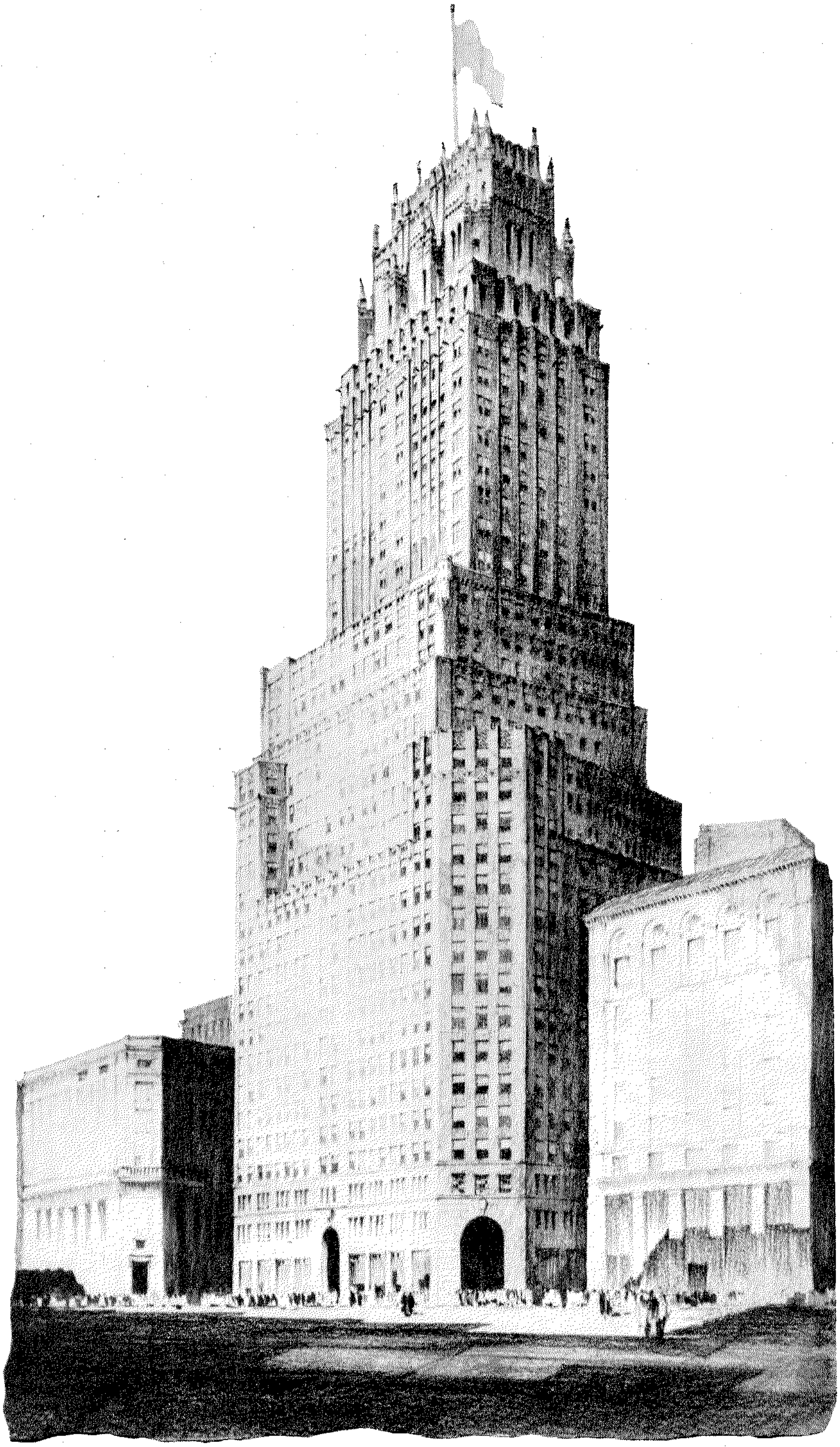
THE UNIT OF TRANSMISSION AND THE TRANSMISSION REFERENCE SYSTEM 42
By G. H. Gray

METHODS OF LOCATING CROSSTALK FAULTS ON LOADED CABLES 45
By K. E. Latimer

THE "SOLID BACK" CARBON BUTTON TELEPHONE TRANSMITTER 49
By L. C. Pocock

THE CREED HIGH SPEED MORSE PRINTING TELEGRAPH SYSTEM 52
By F. G. Creed





INTERNATIONAL SYSTEM HEADQUARTERS BUILDING

67 Broad Street New York

Architect's drawing showing how the building will look after the final half has been added

A Rural Rotary Automatic Telephone System Installed at Herrliberg

By W. HATTON

Les Laboratoires Standard, Paris

THE demand for rural automatic telephone equipment is becoming more insistent in Europe, and the various Telephone Administrations are at present engaged in studying the special conditions to be encountered in this type of service. Advanced programmes are being prepared, notably in Switzerland. These, when completed, will provide the smallest community with a telephone service of the same high grade as that enjoyed in large towns.

The modern tendency is to consider a large town as the switching centre for the surrounding small rural exchanges, and to provide for full automatic inter-connection between all the subscribers of the network so formed. This general idea is capable of development in several different directions. For example, automatic metering on a zone and time basis may be introduced, or a uniform rate may be charged for connections terminating within the network. Subdivision of the network may be effected with the larger villages as sub-centres. In cases where it is found more expedient to inter-connect the sub-centres on a semi-automatic or manual basis, a second line of development may be followed.

There are many communities, however, where a simpler service would answer, and where the full automatic operation may be restricted to purely local calls. Power driven equipment for this class has already been tried with success in Denmark and Belgium and, on December 1, 1927, an installation of this type was opened for public service by the Swiss Telephone Administration authorities at Herrliberg, situated on Lake Zürich and distant about 15 kilometres from the town of Zürich itself (Figure 1).

Equipment

The installation at Herrliberg is of the type known as the No. 7000 Automatic Rural, which is built up of self contained units completely assembled, wired, and tested in the factory. Standard sizes of equipment are manufactured for capacities varying from 100 to 400 lines. If the development ever exceeds the anticipated figures, the capacity may be increased to 600 lines. At Herrliberg, equipment was furnished for 100 lines, 10 two-party lines, and 6 junctions. At the cut-over, 77 subscribers were connected, including 6 two-party lines. Four main units were supplied, i.e.,

One line and junction relay unit.
Two link circuit units.
One register circuit unit.

Figures 2 and 3 show respectively the front and rear of the link and register unit after installation and with dust covers removed. The plan, Figure 4, shows the floor space occupied, and the disposition of the units.

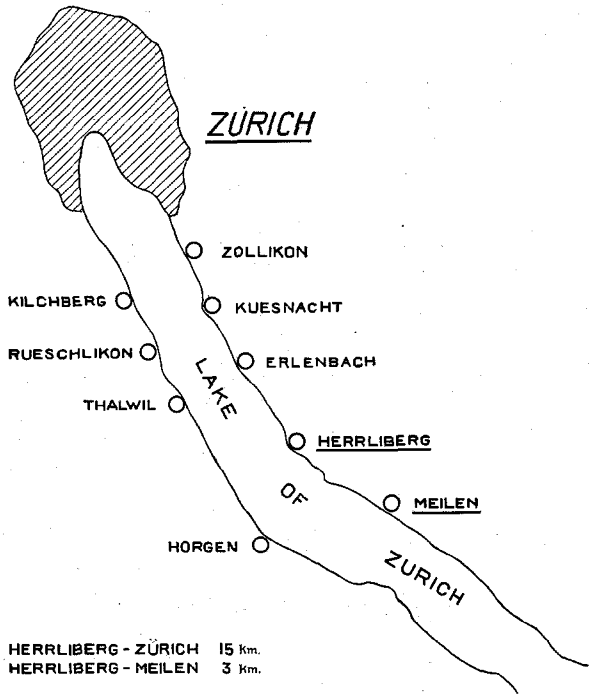


Figure 1—Part of Lake Zürich.

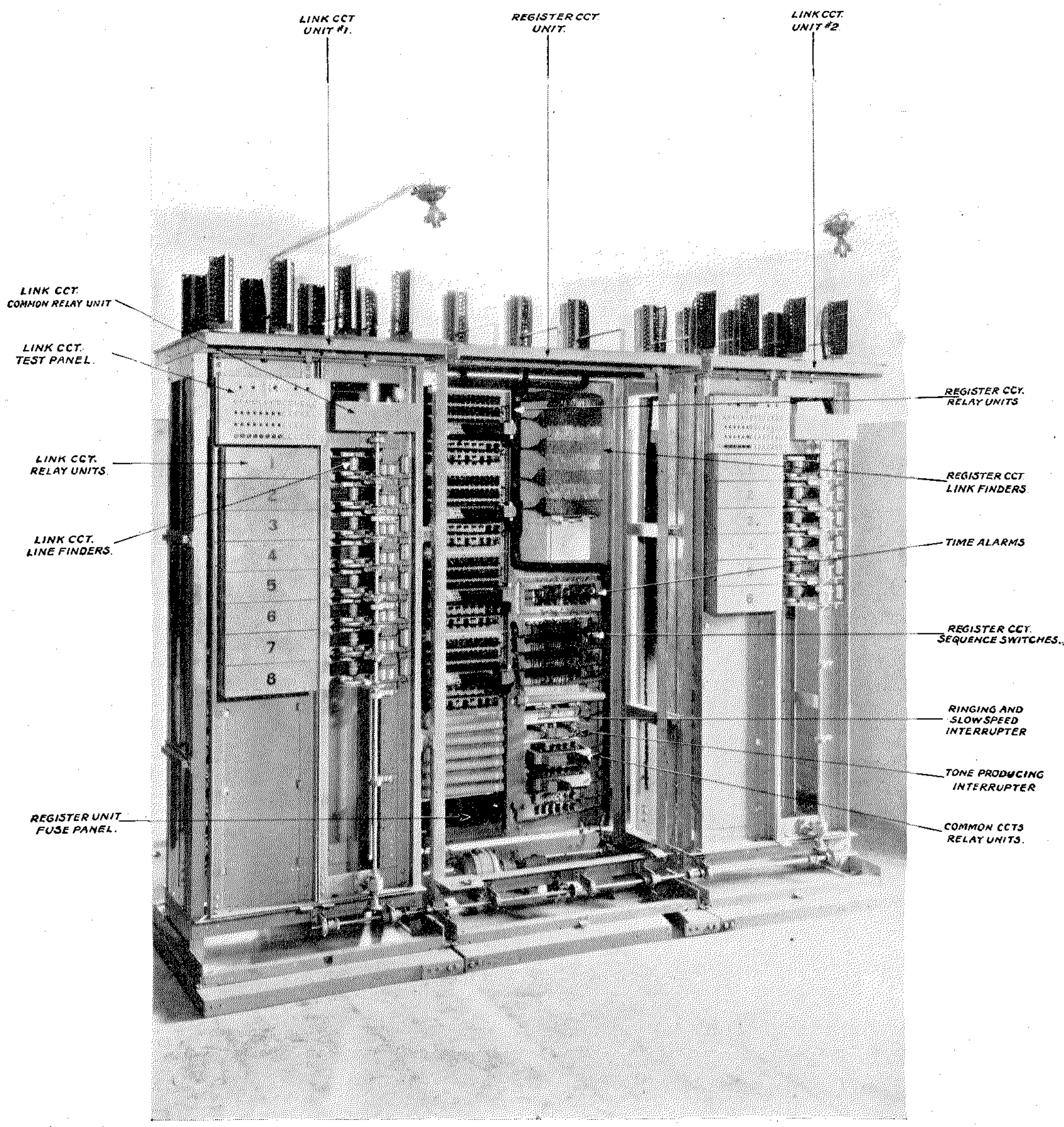

LINK CCT UNIT #1.
REGISTER CCT. UNIT.
LINK CCT. UNIT #2.
LINK CCT. COMMON RELAY UNIT
LINK CCT. TEST PANEL.
LINK CCT. RELAY UNITS.
LINK CCT. LINE FINDERS.
REGISTER UNIT FUSE PANEL.
REGISTER CCY. RELAY UNITS
REGISTER CCT LINK FINDERS
TIME ALARMS
REGISTER CCY. SEQUENCE SWITCHES.
RINGING AND SLOW SPEED INTERRUPTER
TONE PRODUCING INTERRUPTER
COMMON CCTS RELAY UNITS.

Figure 2—Link and Register Units, Front View. Herrliberg Installation.

The line and junction relays are mounted on vertical bays, two bays forming a unit with a capacity of 200 line circuits and 25 junction circuits. The link circuit units have a capacity of 28 circuits, but for the present 14 circuits only are equipped. A single link circuit comprises two 100-point gear driven finders (the construction of which has already been described)[1] and standard flat type relays. One finder is used as a line finder, and the second as a selector. The selector capacity of the circuit

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[1] G. Deakin, "No. 7-A Machine Switching System," *Electrical Communication*, Volume III, No. 3, January, 1925.

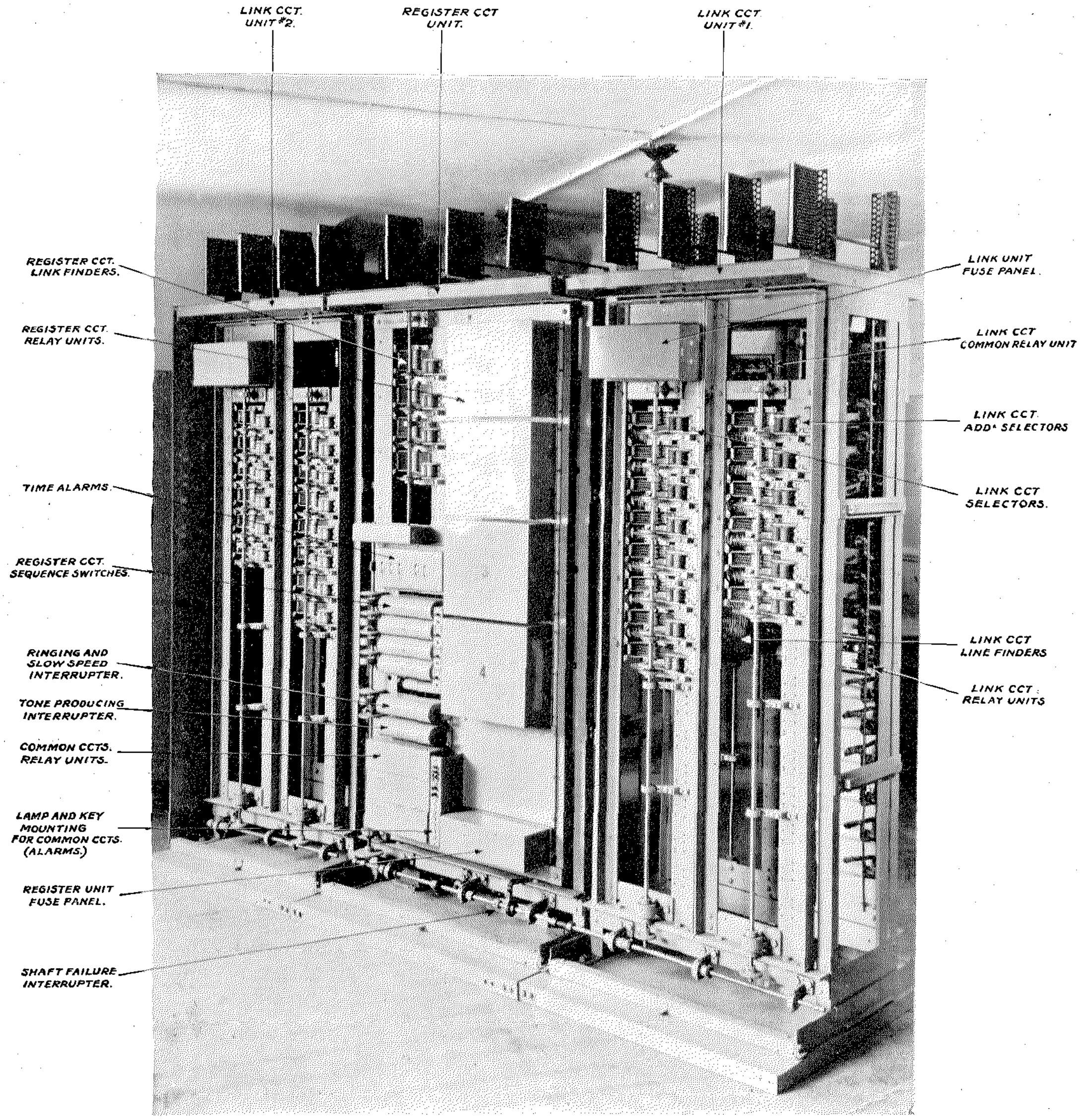

LINK CCT. UNIT #2.
REGISTER CCT UNIT.
LINK CCT UNIT #1.
REGISTER CCT. LINK FINDERS.
REGISTER CCT. RELAY UNITS.
TIME ALARMS.
REGISTER CCT. SEQUENCE SWITCHES.
RINGING AND SLOW SPEED INTERRUPTER.
TONE PRODUCING INTERRUPTER.
COMMON CCTS. RELAY UNITS.
LAMP AND KEY MOUNTING FOR COMMON CCTS. (ALARMS.)
REGISTER UNIT FUSE PANEL.
SHAFT FAILURE INTERRUPTER.
LINK UNIT FUSE PANEL.
LINK CCT COMMON RELAY UNIT
LINK CCT. ADDᴸ SELECTORS
LINK CCT SELECTORS.
LINK CCT LINE FINDERS
LINK CCT RELAY UNITS

Figure 3—Link and Register Units, Rear View. Herrliberg Installation.

may be increased by adding further finders, and space is provided on the link unit for one additional finder per circuit. When the capacity reaches a figure above 200 lines, the additional finders are accommodated on separate bays. Figure 5 illustrates a link unit with covers removed, and it will be seen that the equipment on the front of the unit is mounted on hinged bays, which are shown opened.

The capacity of the register unit is 10 circuits, and the present equipment 4. A complete unit is built up on two vertical bays, each bay accommodating 5 registers. A single register circuit comprises one standard gear-driven sequence switch, one gear-driven finder and flat type relays. The register unit equipped with four circuits may be seen in the centre of Figures 2 and 3. By fully equipping the present units, the Herrliberg installation can therefore easily be extended to carry additional subscribers' lines up to a maximum of 200, including the junction circuits. The three units are driven from a common motor which is fed from the main 48-volt battery, 48 volts being the normal operating potential of the system.

The shaft motor is controlled by a starting circuit which is closed only when the motor is actually required.

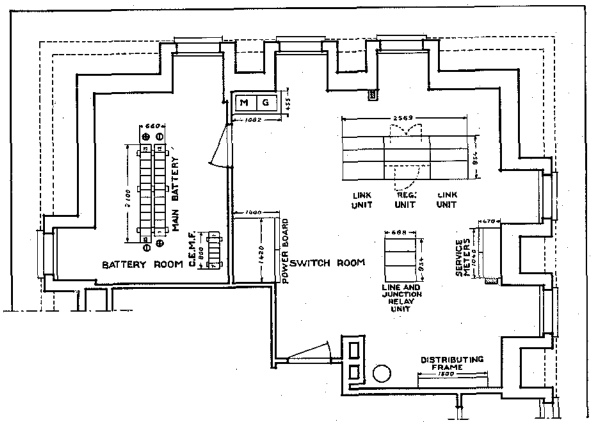


Figure 4—Floor Plan of Herrliberg Installation.

The system is provided with a scheme by means of which fault alarm signals are transferred to Zürich. The alarms are divided into two classes: those requiring prompt action, such as shaft failure, ringing failure and main fuse failure; and those requiring deferred action, such as battery discharge, individual circuit fuse failure, and register circuit alarm.

The subscribers' lines are ordinary two-wire circuits, but as the subscribers' line plant of a rural exchange is not usually of the same high grade as that provided on large installations, each subscriber's line is provided with a fault relay. This relay becomes energised on a fault or failure to dial after 30 seconds, and disconnects the line from the automatic equipment. In addition, it makes engaged a certain test number which is periodically called from Zürich, and the engaged condition of this test number indicates the existence of a faulty line at Herrliberg. The guaranteed operating limits of conductor resistance are 1,000 ohms and of insulation resistance 10,000 ohms, but satisfactory service can be given in cases where the insulation resistance is below this figure. The subscribers' instruments are of the standard type as provided for No. 7-A Machine Switching System, and the guaranteed operating limits of dial speed are 8 steps per second, minimum, and 14 steps per second, maximum.

Two party lines with revertive calling are also connected, and secret service is provided, this being a standard requirement for Switzerland. (See Figure 6.)

Operation

Connections to Zürich

As is usual with small communities such as Herrliberg, the percentage of local calls is very small, most of the traffic being directed to the nearest centre, which, in this case, is the town of Zürich. Four 2-wire junction circuits are provided to carry the traffic between Herrliberg and Zürich, which terminate at Zürich on the short haul toll position. To gain connection with the Zürich operator, the procedure is as follows:

The receiver is removed from the hook, whereupon the calling subscriber at Herrliberg is connected to an idle link circuit, and thereafter to an idle register circuit. On receipt of the dialling tone, the calling subscriber dials the single digit zero. The link circuit selector is then set in motion and hunts under the control of the register circuit. When a free junction to Zürich is found, the register circuit is released and the through connection is made in the link circuit. The Herrliberg subscriber is now connected through to the Zürich operator who controls the further progress of the connection. At present, all effective connections are "ticketed" in the regular manner.

Automatic metering of the calling party on outgoing calls to Zürich is not introduced at Herrliberg, but this feature may be added later by modifying the junction circuits, in which case the service meter of the calling party would be operated 2, 3 or 5 times at the beginning of each three-minute conversation period. Metering would commence when the called party

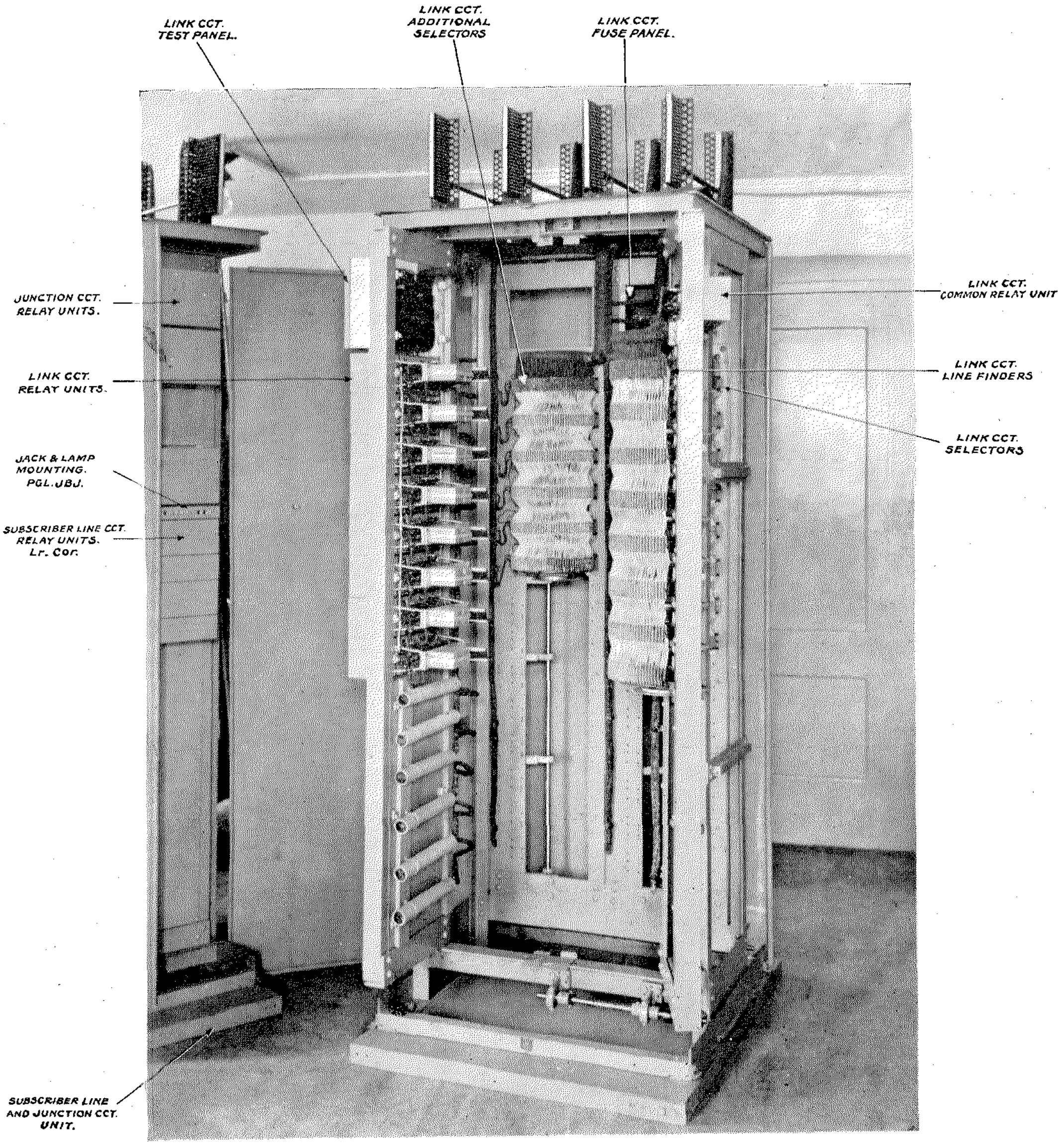

LINK CCT. TEST PANEL.
LINK CCT. ADDITIONAL SELECTORS
LINK CCT. FUSE PANEL.
LINK CCT. COMMON RELAY UNIT
LINK CCT. LINE FINDERS
LINK CCT. SELECTORS
JUNCTION CCT. RELAY UNITS.
LINK CCT. RELAY UNITS.
JACK & LAMP MOUNTING. PGL.JBJ.
SUBSCRIBER LINE CCT. RELAY UNITS. Lr. Cor.
SUBSCRIBER LINE AND JUNCTION CCT. UNIT.

Figure 5—Link Circuit Unit. Herrliberg Installation.

replies or, in the case of non-through signalling cord circuits, when the operator depresses the metering start key.

For connections from Zürich to Herrliberg, the toll operator selects an idle junction, and thereafter dials the number of the wanted party at Herrliberg. The junction in this case appears at Herrliberg as a regular subscriber's line, and the toll operator is connected to the ordinary link and register circuits.

Connections to Meilen

Tie line service is provided between Herrliberg and the neighbouring village of Meilen. The

Herrliberg subscriber dials the single digit 9 and becomes automatically connected to the operator at Meilen, who then completes the connection. For connections from Meilen to Herrliberg, the operator selects an idle junction and then dials the number of the wanted party at Herrliberg.

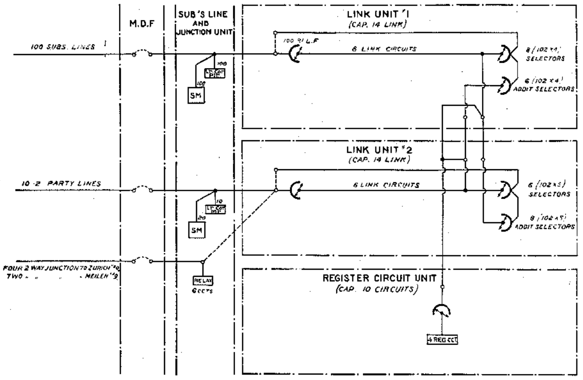

M.D.F
SUB'S LINE AND JUNCTION UNIT
LINK UNIT #1 (CAP. 14 LINK)
100 SUBS. LINES
100 2/ L.F
6 LINK CIRCUITS
8 (102 x 4) SELECTORS
6 (102 x 4) ADDIT SELECTORS
100
LC. COT. DIF.
100
SM
LINK UNIT #2 (CAP. 14 LINK)
10 -2 PARTY LINES
6 LINK CIRCUITS
6 (102 x 5) SELECTORS
8 (102 x 5) ADDIT SELECTORS
10
LC. COT. DIF.
20
SM
FOUR 2 WAY JUNCTION TO ZURICH "0
TWO " " " MEILEN "9
RELAY 6 CCTS
REGISTER CIRCUIT UNIT (CAP. 10 CIRCUITS)
4 REG CCT

Figure 6—Junction Diagram.

Local Connections

For local connection the calling subscriber lifts the receiver and, on receipt of the dialling tone, dials the three digits forming the number of the wanted subscriber. If the line is free, ringing current is connected and, until the wanted subscriber replies, the calling party receives a ringing tone. The release of the connection is normally under the control of the calling subscriber, but an interesting feature of the system is the provision of delayed back release, that is, the forced release of the connection in the event of the calling subscriber holding for thirty seconds after the called subscriber has restored the receiver. No time limit is provided on local connections; at the termination, the service meter of the calling subscriber is automatically operated once.

Maintenance Records

The subscribers of Herrliberg were, from the outset, in favour of the introduction of automatic equipment. After five months of service, an enquiry was distributed to all subscribers with the following results:

Number of enquiries mailed...........	80
Number of replies received............	59
Number of subscribers satisfied........	40
Number of subscribers very well satisfied	17
Number of subscribers not satisfied....	2

Of the two dissatisfied cases, the first was found to be due to an error in the directory, and the second to faulty installation at the subscriber's premises.

The amount of traffic dealt with during the first six months of service may be seen from the records below:

MAINTENANCE RECORDS
FROM DECEMBER, 1927, TO MAY, 1928, INCLUSIVE

	Dec. '27	Jan. '28	Feb. '28	Mar. '28	Apr. '28	May '28
Regular Subscribers....................................	71	71	72	72	76	77
2-Party Subscribers....................................	6 (3x2)	6 (3x2)	6 (3x2)	6 (3x2)	6 (3x2)	6 (3x2)
Total number of subscribers............................	77	77	78	78	82	83
Total number of local connections......................	836	1252	1045	1311	1363	1528
Total number of toll connections.......................	3236	3161	2963	3519	3457	3543
Total faults found and cleared.........................	5	5	3	2	3	3
Total man-hours required for maintenance, including battery charging and travelling time.........................	18¾	29¾	18	26	33½	32

Further particulars on the No. 7000 Rural Automatic Equipment are given in an article in *Electrical Communication*, Volume VI, No. 2, October, 1927, on "An Automatic Telephone System for Rural Exchanges," by L. J. Saltoft.

Control of Release Time of Relays in Automatic Telephone Systems

By R. St.G. TERRY

Engineering Department, Standard Telephones and Cables, Limited.

ALL automatic telephone systems at present in operation use slow-acting relays and a study of their operation shows that the releasing and operating time of any given relay is capable of variation. In addition, it is well known that if a number of relays of any given design made by modern repetition methods are tested, lack of uniformity in timing will be revealed. This variation necessitates large timing margins and these have been provided without much difficulty in the more elementary applications.

Automatic Telephone Systems for large areas such as London or Paris involve an increase in the number and complexity of the time relations which exist between different relays. In some cases the release time of a particular relay cannot be allowed to vary up or down very much, so that some precise method of adjustment is necessary. At times the effect of a faulty adjustment is to derange the working of distant apparatus, possibly in another exchange, in which case the method used largely at the present time of adjusting a relay until it enables associated apparatus to function correctly cannot be relied upon.

To satisfy the new conditions it is necessary to have a method of controlling release time which deals with the relay as a unit. If such a method is forthcoming, the circuit designer will be aided in his efforts to simplify and cheapen automatic equipment by having a more satisfactory instrument at his disposal; and the task of the maintenance staff will be made easier.

Before the methods of controlling release time of relays can be formulated and considered, it is necessary to know how to predict the release time of a particular relay under given conditions. This part of the subject has been considered by Chechelovsky[1], but will be discussed here in greater detail to explain how variations in components of the relay affect its release time.

Consider a relay having a copper ring or slug encircling its core. On opening the circuit of the relay there is, as a rule, little sparking, and the current falls to zero very rapidly. The flux in the magnetic circuit then has a value dependent upon the previous excitation, and it commences to die away. The decay of flux induces an e.m.f. causing currents in any closed circuits which happen to link with the magnetic circuits. The currents thus set up tend to maintain the flux and would do so indefinitely if these circuits had no resistance. Actually the resistance of the slug of a telephone relay is such that the flux falls to a low value in about one second or less and the relay releases. Release occurs at the instant when the magnetising force provided by the eddy currents reaches a value just insufficient to provide enough flux to resist the forces tending to restore the armature to normal. A further period is occupied while the armature moves from the core to the back stop, but this is negligible compared with the time required for the flux decay.

The factors determining the release time are:

1. The reluctance of the magnetic circuit.

This involves:

a. Quality of iron and method of annealing.
b. Thickness and composition of finish.
c. Dimensions of core, polepiece and armature.
d. Operated air gaps, i.e., air gaps present when armature is operated.

2. The conductivity and number of turns of the closed electric circuits linked with the magnetic circuit.

Included under this heading are:

a. Dimensions and conductivity of the slug.
b. Dimensions and conductivity of all parts such as polepiece, core, armature, metal spool cheeks.

---

[1] C. Chechelovsky, Physical Laboratory, Bell Telephone Manufacturing Company, Antwerp, "Etude sur le Temps de Fonctionnement et de Relâchement des Relais Téléphoniques," Mémoire Couronné au Concours de la Fondation George Montefiore. Bulletin Institut Electrotechnique Montefiore, 1925-1926.

c. Thickness and conductivity of finish.
d. Short circuited turns in the winding.

3. Magnetic leakage.

This depends upon the position of slugs and windings, the shape and permeability of the magnetic circuit and the excitation.

4. Initial excitation.

This is the product of the circuit current and the number of turns on the coil.

5. Excitation at which release takes place.

This is dependent on:

a. Operated load (itself dependent on spring stiffness and adjustment).
b. The size, permeability and coercive force of the magnetic circuit.
c. Initial excitation.
d. Position of the winding or slug providing the excitation.

Each of the quantities above is subject to some variation, and the release time variation is compounded from them all. It is not surprising therefore that large margins are necessary if the natural limits consequent upon the use of commercial materials are allowed. There are two ways of reducing these limits. Each one of the quantities concerned may have its limits restricted, or advantage may be taken of the fact that adjustments may be used to counteract the effect of some of the variables. To accomplish this the adjuster must have some simple means of knowing what adjustments to make; in other words, he needs a test to indicate directly whether the release time of the relay will be within the prescribed limits or not. Moreover, since wear and handling obviously will affect the release time, the maintenance staff must be in a position to make like tests.

When adjustments are used to counteract the effect of variations in components, it is still necessary to limit the dimensions of components; otherwise excessive adjustment may be necessary. Thus whatever plan is followed, limits are necessary on all components, but where an overall limit is imposed individual limits need not be so close.

Examination of the component variables is sufficient in itself to show that no simple theoretical expression can be devised for calculating release time, but if constant permeability and negligible leakage are assumed a simple and interesting formula can be obtained.

Let I = Current in main coil.
ϕ = Flux.
N = Turns in main coil.
K = A Constant.
T = Time.
n = Turns in short circuited coil or slug.
r = Resistance of short circuited coil or slug.
r_c = Effective resistance of the core, pole-piece and armature to eddy currents.

And let the suffixes s and r indicate saturated (i.e., initial) and release conditions, respectively.

Then for steady values of flux,

$$\phi = K.\ IN: \qquad (1)$$

and if the flux is changing with time,

$$IN = \frac{\phi}{K} + \left(\frac{n^2}{r} + \frac{1}{r_c}\right)\frac{d\phi}{dt}, \qquad (2)$$

which is analogous to the well known equation

$$E = RI + L\frac{di}{dt};$$

obviously, the magneto motive force has to overcome the reluctance of the magnetic circuit and neutralize a counter magneto motive force provided by the eddy currents.

At the moment the magnetising coil circuit is broken (assuming no spark),

$$IN = 0;$$

whence from (2) $\frac{\phi}{K} = -\left(\frac{1}{r_c} + \frac{n^2}{r}\right)\frac{d\phi}{dt}$;

and $dt = -K\left(\frac{1}{r_c} + \frac{n^2}{r}\right)\frac{d\phi}{\phi}$;

therefore

$$\int_{T_s}^{T_r} dt = -K\left(\frac{1}{r_c} + \frac{n^2}{r}\right)\int_{\phi_s}^{\phi_r}\frac{d\phi}{\phi};$$

and $T_s - T_r = -K\left(\frac{1}{r_c} + \frac{n^2}{r}\right)(\log_e \phi_s - \log_e \phi_r)$.

From this equation and (1);

$$\text{Time of release} = K\left(\frac{1}{r_c} + \frac{n^2}{r}\right)\log_e \frac{I_s}{I_r} \qquad (3)$$

A more accurate expression results if the permeability is considered to vary with the flux density whilst the flux distribution remains constant. Equation (2) can then be restated as

$$IN = \frac{\phi}{R} + \left(C_1 \frac{n^2}{r} + \frac{C_2}{r_c} \right) \frac{d\phi}{dt} \qquad (4)$$

in which C_1 is the leakage factor corresponding to the size and position of damping winding or slug,

C_2 is the leakage factor for the core, and

R is a variable.

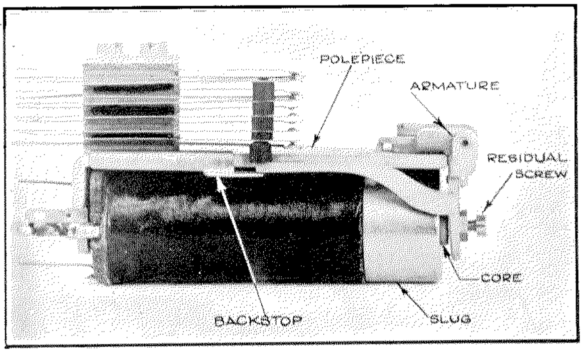
$$\text{Then } \int_{T_s}^{T_r} dt = -\left(C_1 \frac{n^2}{r} + \frac{C_2}{r_c} \right) \int_{\phi_s}^{\phi_r} R \frac{d\phi}{\phi};$$

$$\text{and time of release} = \left(C_1 \frac{n^2}{r} + \frac{C_2}{r_c} \right) f(I_s, I_r) \qquad (5)$$

Experimental results will now be described and related to the theory. Taking any particular relay there are three things that can be altered:

1. Initial excitation.
2. Operated load.
3. Operated air gap.

The last two clearly fix the releasing excitation; and if we can measure the latter directly, it will be possible to replace two variables by one. The actual release excitation is that provided by the slug, and its value will depend upon the excitation obtaining just before the circuit is broken. This quantity cannot be measured directly but we have a nearly related variable in the release ampere turns measured by means of a resistance and milliammeter in series with the coil. If the release currents for a given adjustment are measured after different values of excitation and the results are plotted, curves as in Figure 1 are obtained.



No. 4700 Type Relay, as Used in Step-by-step Automatic Telephone Systems.

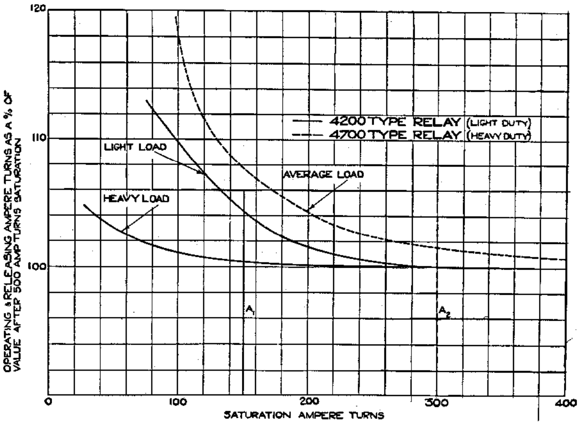


Figure 1—Effect of Initial Excitation on Release Ampere Turns.

Above a value, A, the value of the release ampere turns is practically independent of the previous excitation. A convenient definition of release current is therefore the value obtained after an excitation A. In the case of 4700 type relays used in the step-by-step automatic system, this can be taken as 300 ampere turns.

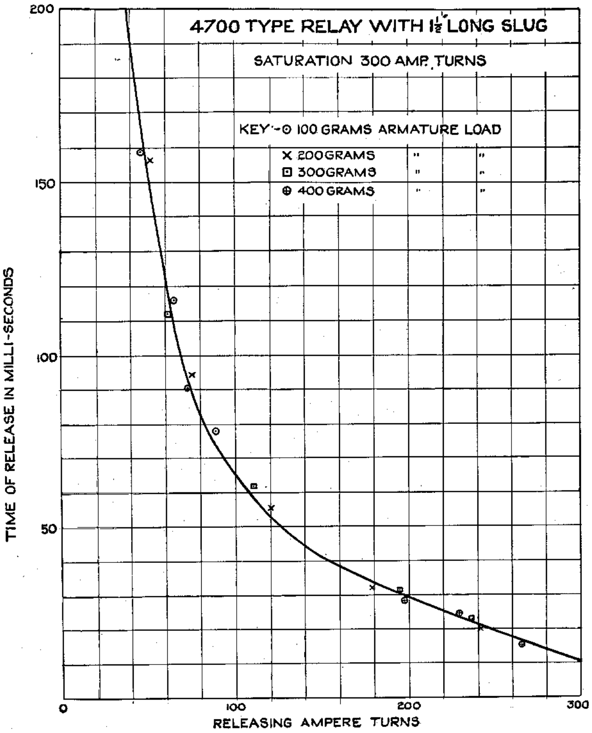


Figure 2—Variation of Release Time with Release Ampere Turns.

The curve in Figure 2 is typical of the results when release time is plotted against release ampere turns, measurements being made after one value of excitation. It will be noticed that although each value of release ampere turns has been obtained with a wide range of load and air gap, the points all lie on one smooth curve. This means that relays similar in all respects, except load and air gap, tested under the same conditions will have the same release time provided that their release ampere turns measured in the standard way are identical. The air gap may be due to the residual screw, oblique armature contact, or surface finish, such as zinc plating, without affecting the result.

Taking the release ampere turns measured after standard saturation as the criterion of adjustment, we can proceed to explore the release time characteristics of any given relay. A typical set of curves is shown in Figure 3. If a number of such sets of curves from relays having different slugs or short circuited windings but the same magnetic circuit are compared, it will be found that curves such as Figure 4 can be drawn.

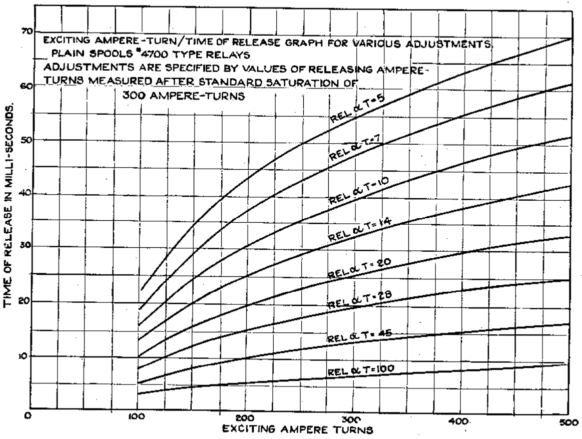


Figure 3—Release Time Characteristic of a Relay.

Starting with a length of slug = −E instead of 0, the release time is proportional to $\frac{n^2}{r}$. The value E is the size of a short circuited winding to fit relays similar to those tested, but composed of iron having infinite electrical resistance, to give the same release time as the actual relay. It can be called the "slug equivalent" of the core, polepiece and armature; and depends upon the resistivity of the magnetic material. Thus, the release time of a relay can be made very small by the use of nickel-iron alloys, silicon-iron alloys, or by laminating the structure.

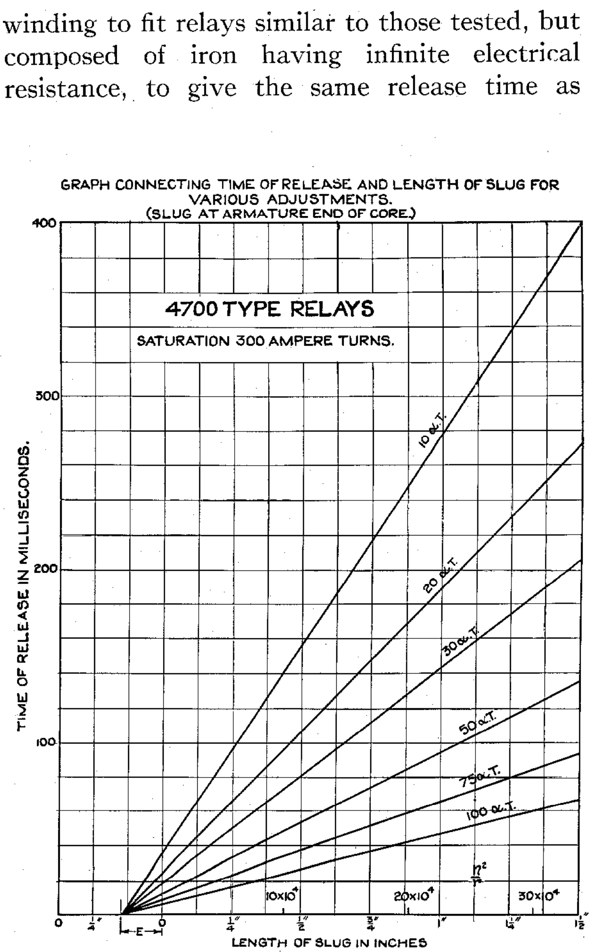


Figure 4—Variation of Release Time with Length cf Slug.

The slug equivalent for a given relay is not a constant but varies with release ampere turns and saturation ampere turns. Figure 4 does not show this because the scale is small and the saturation ampere turns were kept unchanged. The reason for the variation is that the flux distribution in the iron parts of the relay changes with the flux density so that the distribution of eddy currents is not the same for high densities as it is for low ones. Thus C_2 in equation (5) is a function of I_s and I_r.

It is also found when using slugs at the terminal end of the spool that the lines on graphs connecting time of release with length of slug curve downwards very slightly. This shows that C_1 is also a variable, decreasing a little with an increase in slug length, but the error introduced by considering C_1 to be a constant is negligible.

The time of release of a relay having any size of slug therefore can be determined if graphs similar to Figure 3, drawn for two values of $\frac{n^2}{r}$, are available.

The fact has thus been established that release time can be predicted and that the release time of any *given* relay can be kept within any desired limits by controlling the excitation and release current. To ensure that any one of a large number of relays also releases within the desired time limits, certain other requirements have to be observed.

Taking the five groups of quantities previously cited, it is necessary to examine them in detail to see whether they can be kept constant and whether commercial variations will affect the release time to an important extent.

1. *Reluctance of the magnetic circuit.*

The simple formula (3) suggests that the release time is approximately proportional to the reciprocal of the reluctance. It is necessary therefore to take great care to keep the quality of iron and the annealing process in close agreement with those employed in making the experimental relays. Ordinary piece part limits will keep the value of $\frac{\text{length}}{\text{area}}$ (the dimensions governing reluctance) to within about ± 3% of standard. The thickness of finish, obliquity of contact between armature and core and the operated air gap do not cause trouble so long as the relay can be adjusted to the current tests imposed.

2. *Conductivity and number of turns of the electric circuits linked with the magnetic circuit* $\left(\frac{n^2}{r}+\frac{1}{r_c}\right)$.

This quantity appears as a multiplying factor in the time equation and is therefore important. Ordinary piece part limits will keep the value of the ratio $\frac{\text{length}}{\text{area}}$ for the various parts within about ± 1%, and the conductivity of copper can be kept within ± 2%. The conductivity of the iron used is less easy to control but merits careful attention, especially in the case of relays without slugs. The effect of finish also is quite important on plain (unslugged) relays and the easiest way to deal with it is to use a form of plating having high resistivity, avoiding the use of too thick a coat. In this way the inevitable large percentage changes in plating thickness will have little effect on the release time, since they will be second order variables.

An impedance test at voice frequency shows up short circuited turns, changes in plating, and iron resistivity very well on unslugged relays. On relays with slugs it is difficult to detect faults of this kind, but the effect of change in thickness of plating and of iron resistivity upon the quantity $\left(\frac{n^2}{r}+\frac{1}{r_c}\right)$ is always small compared with the effect of the slug upon that quantity. The number of short circuited turns in slugged relays is rarely great enough to have important detrimental influence upon release times.

3. *Magnetic leakage.*

No changes in release time due to alterations in magnetic leakage have been detected. The only way leakage can be modified when the components of the relay are satisfactory for other reasons is by adjusting the residual screw. The effect is to change the release excitation by varying both the reluctance of the magnetic circuit and the leakage. Figure 2 shows that the relationship of release time to release ampere turns is independent of this effect, for in obtaining this curve, a range of residual gap of 0—20 mils was used. Additional evidence of the small effect of commercial differences in piece parts on magnetic leakage is provided by the previously mentioned fact that there is not more than about 5% difference in release time between relays having equal length slugs, one relay having its slug at the armature end of the core and the other having its slug at the terminal end.

4. *Initial Excitation.*

The limits of the two components, current and turns, are easily evaluated.

5. *Release Excitation.*

This is brought within prescribed limits by adjustment. It is necessary to ensure, however, that the hold (upper limit of release) and release tests are made in the same way as those used in the experiments, i.e., after an excitation equal to or greater than A in Figure 1.

After reviewing the steps necessary to ensure a known degree of uniformity for a quantity of slow releasing relays, it must be remembered that most of the work is done during manufacture. The actual tests used by the maintenance staff would be the same as those usually employed with the addition of two current tests. Thus, in the case of a 4700 type relay as used in step-by-step automatic exchanges, the following tests would be given:

a. *Current Tests.*
   1. Saturation.
   2. Hold.
   3. Release.
   Additional tests to control minimum and maximum release times.
   4. Non-operate.
   5. Operate.

b. *Mechanical Tests.*
   1. Gauging.
   2. General Clearances, etc.

"Saturation" is not really a test but is a measure which should be taken to standardise the condition of the relay before making *any* tests. The current employed for saturation is usually the normal circuit current so that no measurement is necessary.

A better idea of the advantages of the use of these additional tests may be obtained by considering the case of relays with which the same care has been taken in regard to dimensions, materials and processes, but which have been adjusted to operating and non-operating currents only.

For a given relay and method of tests, release current, governing release excitation, depends upon:

a. Operated air gap.
b. Operated load.

In step-by-step system relay practice, the operated load will depend upon the contact separation and upon the "follow," the stiffness of the springs, and the contact pressure on the break contacts. Usually the operating current is fixed by the load at the beginning of the armature stroke, so that the amount of load applied later in the stroke by front contacts, etc., can be varied considerably without changing the operating current. Thus, the only help the operate and non-operate tests give is in controlling the back contact pressure. Even this is done very imperfectly because the contact separation also affects the pressure.

The operated air gap on slow releasing relays is usually "zero." This means that it consists of a certain amount of zinc or nickel plating and air bounded by two surfaces which may be neither flat nor parallel. It is in fact subject to changes which, although small, are a large percentage of the average value.

The combined effect of these causes is that the release current of ordinary (i.e., without hold and release tests) slow releasing relays may be anything from zero up to about half the operating current, and the release time varies correspondingly.

In design, the hold and release test values are normally fixed so that a reasonable adjustment margin exists when all the piece parts, etc., are at either extreme. It is possible, however, to restrict the range of release time to a much smaller amount than this allows, by making the hold and release tests more nearly equal. If free use of the residual gap adjustment can be allowed, as is usual, these tests can be made to differ by no more than 10% and a constancy of release time can thereby be achieved, quite impossible by the other method. The value of the ratio $\frac{\text{Maximum Release Time}}{\text{Minimum Release Time}}$ of course depends upon the exchange voltage limits and the spring combination to some extent, but the following figures can be taken as representative of good practice:

	Ordinary Operate and Non-operate Method	Hold and Release Method: Full Margins	Hold and Release Method: Minimum Margins
$\frac{\text{Maximum Release Time}}{\text{Minimum Release Time}}$	From 3 to 4	2.5	1.2

In the first two cases above, the windings have been assumed to be of the form:

N turns minimum of No. X gauge copper wire.
Resistance = R ohms ± 5%.

In the last case the winding has been taken as N turns exactly of No. X gauge copper wire made up to R ohms ± 5% by resistance wire.

From the point of view of release time control, it is better and cheaper to wind coils to exact turns and to within ±10% resistance limits than to have a minimum turn requirement and ± 5% resistance limits. Additional advantages of this practice are that it is simpler to detect short circuited turns, and adjustment is a little easier.

The case here considered has been the release of a relay from a steady excitation when there is no external magnetic field to influence it. In actual practice, it is usual to find that the current has not quite reached the steady state, and moreover that external magnetic influences may be present.

Experiment shows that if a relay is energised for a short period and then released, the length of time of energisation profoundly affects the release time. It is also found that so long as the operating current is small compared with the exciting current (say less than a quarter of it) its actual value has no influence on the release times. Figure 5 shows how the release time varies with the period of energisation for different values of excitation and release ampere turns. It will be noticed that an increase in excitation is relatively more valuable for very short periods than it is for long periods of energisation. Also a short slug gives better results than does a longer one when the period of energisation is short.

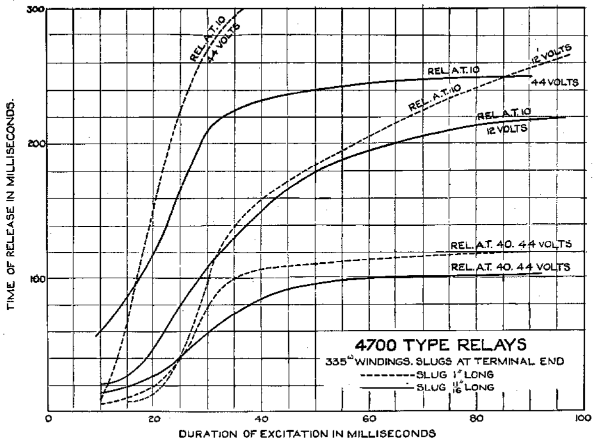


Figure 5—Variation of Release Time with Duration of Excitation.

When a certain release time is wanted from a relay which is energised for a short period, the corresponding release time for full excitation is determined and the appropriate hold and release tests are specified. This ensures uniformity of performance in the same way as it does for fully excited relays, but it is evident that, in addition, any changes in the period of energisation must also be allowed for or eliminated.

External magnetic fields, commonly referred to as cross fire, have an important influence on the release time of relays. A relay magnetised to the same polarity mounted beside the test relay will reduce its release time. If the polarity of the adjacent relay is opposite to that of the test relay, the release time of the latter will be increased. Such disturbing effects are usually present without being sought, but they may on occasion render useful service. In addition to these influences, there are several other electrical means of modifying the release time of relays which are employed either to augment or replace the effect of a slug. The following are examples of these methods:

1. Shunting the relay with a condenser in series with a resistance.
2. Shunting the relay with a non-inductive resistance.
3. Shunting the relay with an inductive resistance.

In all these cases some means is adopted for delaying or accelerating the fall of the flux from the initial value to the releasing value, and in consequence the "hold" and "release" current test is the logical way of ensuring the desired degree of uniformity.

Intercall Selector System on the Swedish State Railway

By IVAR BILLING

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IN AN article appearing in "Teknisk Tidskrift," Stockholm, in 1923, a complete description was given of the train despatching system with selective calling of way stations from a central point, as supplied by the Standard Electric, and to a large extent adopted by the Swedish Railway Administration. This system is also extensively in use in Great Britain, Belgium, Spain, and in other European countries as well as in India, South Africa, the Federal Malay States, Australia, America, and other parts of the world. It has the merit that any of a number of way stations connected in parallel to a metallic line can be called easily without the other stations being simultaneously called or otherwise disturbed, a feature which renders it particularly suitable for railway application. As is well known, this type of service requires facilities for the rapid delivery of messages over great distances with full guarantee of safe transmission between the responsible persons, and without employing expensive trained telegraph operators.

The system is in constant use by the State Railways and has expanded greatly, so that the 3,500 km. of lines and 440 way stations equipped with selectors in 1923 have increased in 1928 to 6,150 km. of lines and 730 way stations. During this time the use of the selector system has increased also on the privately-owned railways of Sweden. In addition to the Railway Companies mentioned in the previous article, i.e., the tunnel railway of the Luossavaara-Kiirunavaara Company comprising a section of 3 km. of line and 10 selector sets, and the Stockholm-Roslagen railways, whose 55 km. line Stockholm-Rimbo has 18 selector sets, there now exist, in the Västergotland-Göteborg Railway with 130 km. of line, the Göteborg-Skara line with 33 selector sets, and the Eskilstuna-Oxelösund line of the Trafik A/B Grängesberg-Oxelösund Railways with 103 km. line and 32 selector sets. The private railways in Sweden accordingly have at present a total of 291 km. line with 93 selector sets in use.

As is well known, there are two systems supplied by the International Standard Electric Corporation:

(i) The "traffic control," "train despatching" or "centralised" system. All ringing is done by a single traffic controller, who can call up any station. In this system, stations cannot call one another directly, but only through the agency of the controller.

(ii) The "Intercall" system, in which by individual selection any station on the same telephone line can call, directly, any other on that line, without a controller.

Most of the lines in Sweden are in accordance with (i). The Eskilstuna-Oxelösund equipment, however, is in accordance with (ii). As this is the first time that the "local calling" system (ii) has been used in Sweden, as it was developed to cover the demand for a system not disturbed by power lines, electric railways, etc., and as new types of apparatus have been introduced into it, a more detailed description of it will here be given.

The signalling arrangements of the intercall system (ii) are similar to those of the traffic control system (i), i.e., selectors are operated by means of A. C. impulses through condensers. The means of producing the impulses is, however, different. In the train control system the impulses are obtained by connecting a signalling battery to the circuit through a smoothing circuit, and then making a series of reversals of the connections of the battery in accordance with some predetermined code. In the intercall system, the A. C. impulses are produced in exactly the same manner that speech currents are produced in the well-known retardation coil cord circuit. The signalling battery is permanently connected to the line through a network of comparatively high impedance at signalling frequency, the function of the microphone, in the case referred to, being performed by a clockwork key which periodically short-circuits the line in accordance with the predetermined code.

As in the system (i), only the selector at the one station which is set to the code signal in question moves forward to the ringing position. The bell is operated by a local battery.

The particular form of the intercall system above described is known as the non-grounded system. There is also another form of the system in which the signalling battery is applied between the two wires and ground. This form requires less battery power, but is more subject to interference from electric power or railway lines.

Non-grounded intercall selector system

The way stations on an intercall selector system communicate through a metallic loop to which they are all connected in parallel. For selective calling one battery supply set is installed. This can be placed where desired along the line, preferably, however, at the middle, in order to reduce the voltage of the line battery necessary for reliable operation. Way station equipments are installed at the various points, each consisting of a table or wall set fitted with an adjustable selector key to make calls, and a selector set with selector to receive calls.

Where it is found necessary, a special key for "common signal" and "time signal" is added as for the Eskilstuna-Oxelösund line. The battery supply set shown in Figure 2 consists of the following parts: (1) Two ballast lamps, whose characteristics are adjusted for properly limiting the signalling current; (2) Condensers connected in parallel with an ohmic resistance and a retardation coil, which together with the ballast lamps have high series impedance at signalling frequencies essential for the operation of the system; (3) A repeating coil with windings evenly divided and connected to the telephone line, to give high impedance between the wires for the speaking current; and (4) Three double-throw knife switches of which two are for connecting the lines in two different directions, and the third is for connecting the line battery. The wiring of this apparatus is shown in Figure 1. All parts are static, i.e., not subject to wear. Regulation of the battery voltage is not necessary after the system is in operation, except, of course, that at regular intervals the battery must receive a proper charge.

The line battery consists of accumulators or dry cells. The voltage is adjusted according to the length of the line, and to the number of way stations connected. When the battery is placed near the middle of the line, the voltage may be calculated only for the longest of the line branches on either side of the battery supply set and the number of way stations connected to this branch. On the Eskilstuna-Oxelösund line, 103 km. long and with a total of 32 way stations, for instance, the battery is placed at Flen. The longest section of the line is then Flen-Oxelösund, 62 km., with 18 way stations. The "normal" voltage of the line battery is fixed at 280 volts. This includes a certain margin for drop in voltage, possible low insulation, etc., as the minimum voltage required for this part of the line is about 180 volts. If the battery had been placed at one end of the line, it would have

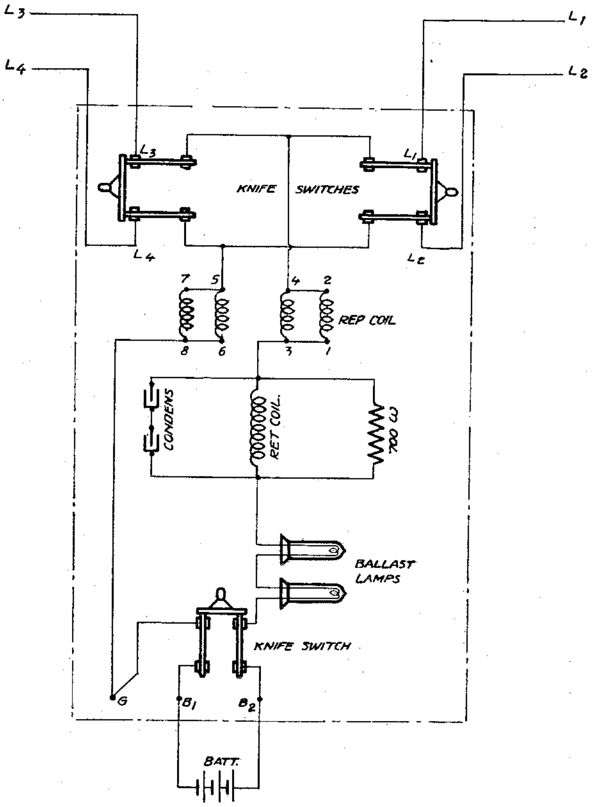

Figure 1—Schematic Diagram of Battery Supply Set.

been necessary to use a "normal" voltage of 360 volts.

In order to protect the battery if short circuits should occur on the line mentioned above, an arrangement with a thermo-electric relay has been installed near the battery supply set and adjusted to disconnect the battery if the line wires at the farthermost end should be short-circuited for eight seconds or more. The maximum current required for a call from the way station nearest to the battery supply set during a period of two seconds—corresponding to the time required for giving a calling signal to a way station—is, however, not sufficient to disconnect the battery.

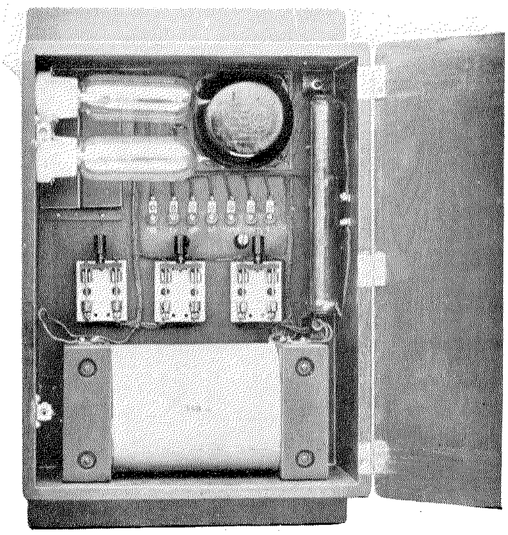

Figure 2—Battery Supply Set.

Equipment of the way stations

The way stations are equipped as shown in Figure 3. To the terminal block, indicated, are connected: The two line wires (L_1 and L_2), two wires to the ringer and transmitter battery (B_1 and B_2), and the necessary connecting wires between the table set and the selector set (L_1, L_2, B_1, B_2, K_1 and K_2). Wall sets can be supplied for use at the way stations. These wall sets are self-contained, comprising not only the telephone equipment and the selector key, but also the selector itself.

The selector set

The wiring of the selector set is shown in the upper part of Figure 3. It contains (Figure 4) the selector itself, above which are a condenser of 1.25 microfarads, and the two symmetrically arranged retardation coils, each of 0.55 ohm, connected to the line L_1 and L_2. In the same set is the 8 ohms ringer, which is connected to the local ringer battery $B_1 - B_2$ by means of contacts on the selector when the latter moves to the ringing position. A special contact in the ringer, connected in series with a condenser, 0.01 microfarad, causes a ringing tone signal to be sent out on the line, as a check that the call is properly received.

The selector, which is hermetically enclosed in a glass cover, consists of a polarised magnet with an armature which operates a stepping mechanism by means of a lever when the magnet coil receives alternate current impulses of approximately 3½ cycles per second (Figure 5). It is non-operative at other frequencies. The selector is accordingly not influenced by ordinary telephone generator current, or current induced from electrified railways or power lines of higher frequencies.

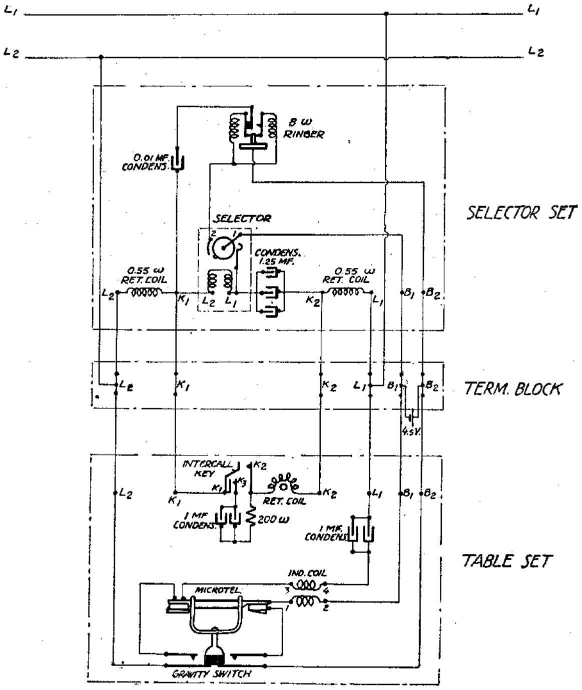

Figure 3—Schematic Diagram of Way Station Equipment.

The same shaft on which is mounted a stepping wheel carries the so-called "code wheel" which is provided with small circumferential holes into which are fitted three code pins. These pins are located at different intervals at different way stations, thus forming the code. A contact "ringing spring" is carried round on the code wheel. The corresponding contact is fixed below the wheel. It requires seventeen impulses to rotate the code wheel sufficiently to bring the ringing contacts together. The total number (17) of impulses is broken into three different groups at each way station code wheel, depending upon the relative positions of the pins. The number of possible combinations of this kind is 78.

Current impulses coming from any calling key pass through the coils of the selector and through the condenser connected in series thereto. The motion of the armature steps the code wheel. Consider a selector 5-6-6 to be operated. The first five impulses from the selector key step the code wheel round five teeth. There is then a period of rest at the key, during which time there is no current charge or discharge through the condenser; consequently, the selector armature returns to its position of rest and releases its hold from the stepping wheel. Code wheels at all stations now tend to return to their normal position; but at the particular stations that have 5 for their initial number the code wheel is held by the code pin, and therefore cannot return. After the pause, the sending key sends six more impulses. The operation is repeated at all stations. The code wheel at the station that has 6 for the second item in its code is again held, all others being released. There is now only one selector that is in an advanced position. After the second pause, the key sends out six more impulses which carry the code wheel to the ringing position, whereupon the selector bell rings for two seconds. During this ringing time, a "tone" is produced on the line by means of an extra contact on the bell at the station called. This assures the sending operator that the called selector has operated. At the end of the ringing period the calling key gives one more impulse which restores the selector to normal position.

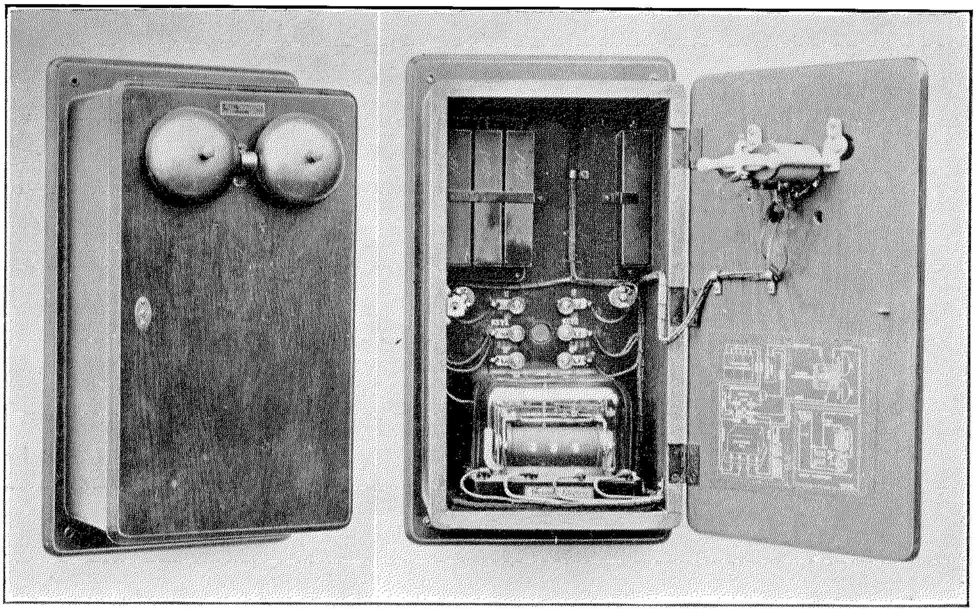

Figure 4—Selector Set.

The magnet coils of the selector have a D. C. resistance of 21,000 ohms. The selector and the condenser connected in series have a total impedance of 35,000 ohms at the calling current frequency of $3\frac{1}{2}$ cycles and more than 1 megohm at the speaking current frequency of 800 cycles.

The circuit diagram of a Table Set is given in the lower part of Figure 3. This set is shown in Figure 6. At the top is the microtelephone resting on a movable cradle, which operates a switch when the microtelephone is removed (Figure 3). This switch connects the microtelephone to the line and closes the circuit of the transmitter battery. It also connects the receiver and the induction coil to the line through a condenser. The Table Set further contains an adjustable (universal) key for originating calls by setting up the special code signal for each of the way stations. This adjustable selector key is characteristic of the intercall selector system. In the system with centralised calling a special central key case contains as many keys as there are way stations on the line, each key being permanently set for a certain signal.

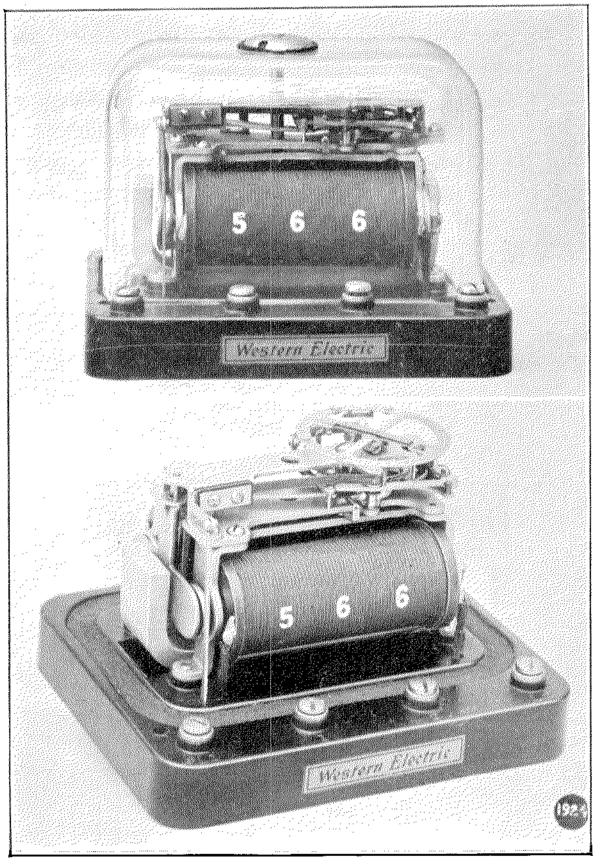

Figure 5—Selector.

Adjustable selector key No. 2196-A

One key is installed in the telephone set at each way station. It consists of a governor controlled clock for the setting of certain calling signals and corresponds to the individual keys at each station in the centralised calling system.

At the front of the key two insulated buttons are arranged coaxially, each associated with a plate sector, one of which is to be seen on the left of the vertical springs in Figure 7. The positions of these sectors, which are controlled by the buttons, are indicated by two pointers with openings (Figure 7) showing the calling signal to which the key is set. In order to set the key to a certain calling signal, for instance 8-4-5, the smaller button is first moved until its pointer arrives at the number 8. Then follows the setting of the larger button until the right pointer is set on 5; in other words, the buttons are used only for the setting of the first and the last (third) impulse group of the calling signal. At the same time the key is automatically set also for the middle impulse group of the calling signal—in this case 4.

Below the two buttons on the front side of the set (Figure 6) is a key handle which can be turned through 90° to the right for the winding of the main spring. When the handle is released, it returns to its normal position, and at the same time the main spring gives the main spindle of the mechanism one turn in 7½ to 8 seconds. Regulation of the speed of the main spindle is obtained by an adjustable governor (Figure 7).

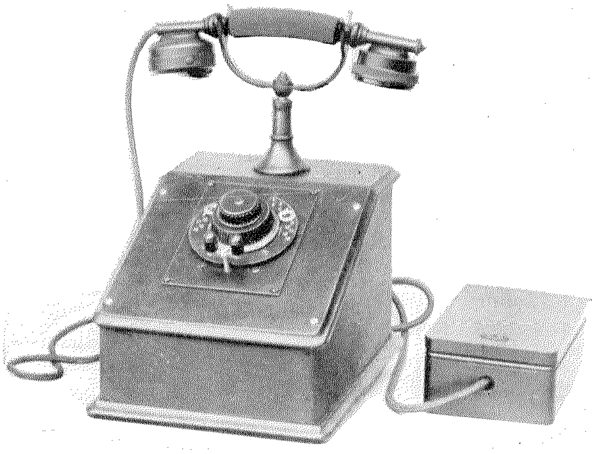

Figure 6—Table Telephone Set.

To the main spindle is fixed a lever which follows the movement of the main spindle and is arranged with a ratchet and spring combination. This ratchet fits into a ratchet wheel which moves freely on the main shaft. The lever is fitted with a pin which, when passing the before mentioned sectors, is pushed outwards, so that the ratchet cannot bring the ratchet wheel along in its motion.

The ratchet wheel is associated with a toothed code wheel, which can also move freely on the main spindle. This code wheel moves accordingly, with an even speed, together with the ratchet wheel, i.e., as long as the ratchet runs freely. When the ratchet wheel, as described, stands still because the ratchet is pushed outwards by the sectors, the code wheel is accordingly also held stationary.

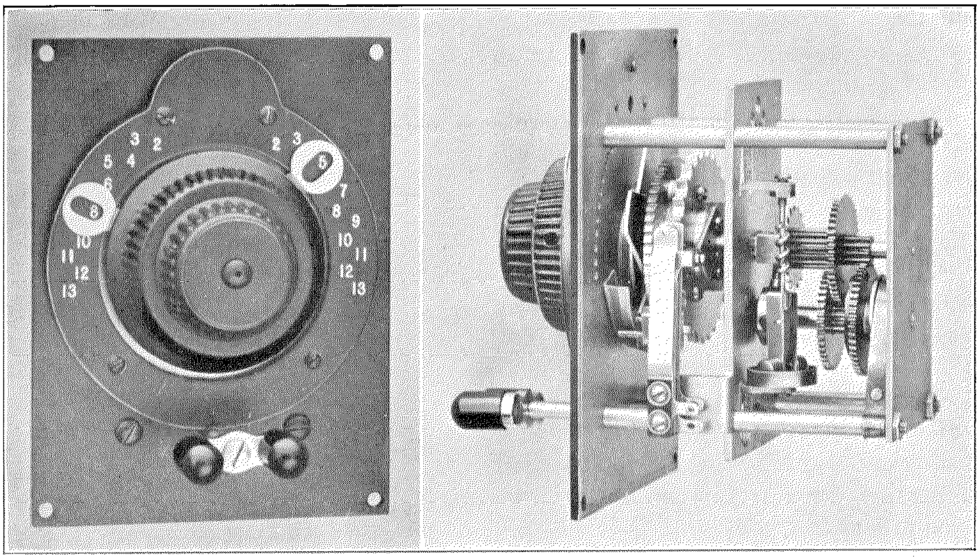

Figure 7—Adjustable Selector Key (Intercall Key).

The teeth of the code wheel open and close the contact between the springs (K_1, K_2, K_3) which are connected to the selector circuit (Figures 3 and 7). These three contact springs constitute the impulsing mechanism, and by their alternate opening and closing allow the condenser associated with each selector on the line to charge and discharge. The corresponding charge and discharge currents from these condensers operate the selectors. The contact between K_1 and K_2 is closed with each passage of a tooth of the code wheel. At the same time the contact K_1 and K_3 is also closed for the purpose of bridging over contact K_1 and K_2 by an arc-quenching device consisting of condensers and resistance coil. The three groups of impulses necessary for the sending of a call are brought about as indicated above, and the interval between the groups is caused by the two sectors. At the receiving selector, the three groups of impulses cause the mechanism to operate as described and to bring it into a ringing position.

To provide for holding the selector in the ringing position, the sending key has a plate segment corresponding to somewhat more than one-quarter turn of the main spindle. When the lever passes this segment, the ratchet wheel and code wheel are held in such a position that the contact springs K_1 and K_2 make contact. As the called selector is then without current, the code wheel remains on its ringing contact, and ringing continues until its release by another impulse from the sending key. When the lever has passed the segment mentioned, its pin drops into a notch and takes the ratchet wheel along until the code wheel gets a tooth gap just in front of the contact spring K_2; this breaks contact K_1 and K_2 and a current impulse passes through all the selectors and effects their release and return to normal. Thereafter the pin of the lever slides out again on the segment in such a position that the code wheel has a tooth gap just in front of K_2, the contact between K_1 and K_2 being still broken, and the key stops, whereby contact K_1 and K_3 is broken and the system has returned to normal position.

Special Key for Common and Time Signals

For the traffic authorities it may often be of importance to call by a common signal a selected group or all stations on the line. An important instance is the giving of the time signal for the daily adjustment of the clocks of the traffic stations. For this purpose the selector telephone plant here described for the line Eskilstuna-Oxelösund has a separate box installed (Figure 8) in the telegraph office in Eskilstuna. This contains three keys, i.e., in the middle, one adjustable selector key No. 2196-A, as described above, by which selective calls for any station can be sent. On each side of this key is a special sending key. These keys are so adjusted that each of them, when used, first sends out seventeen alternating impulses in succession, causing all the selectors on the line to move to ringing position. The key for common signal is so arranged that five short rings follow on all way stations of the line. The key for time signal gives one long and six short rings. On the former signal, all stations have to give an answer in a certain fixed order.

When the time signal is given, however, the way stations do not answer in the telephone, but instead prepare to take the actual time, which is given one minute later, by the repetition of the same time signal, exactly at 9 o'clock.

Characteristics of the Intercall System

The intercall system as supplied to the Trafikaktiebolaget Grängesberg - Oxelösunds Järnvägar has certain features which can be summed up as follows:

(1) All stations have the same equipment.
(2) Each way station can call any of the other way stations.
(3) The battery equipment can be placed wherever desired on the line. It contains no relay or other apparatus requiring adjustment.
(4) As the battery supply set can easily be cut out during tests by means of knife switches, line tests are easy to make.
(5) The system is protected against interference from electric power lines and electric railways, it being evenly balanced and insulated from ground.

The features (2) and (3) are common to both the grounded and non-grounded system for intercalling. In the system with centralised calling as used by the State Railways, however, each connection between two way stations must be established by the despatcher station, i.e., this station is first called and then sets up the selective call. In the United States, Belgium, and other countries where the train despatching system is fully carried out, a person is always present at the despatcher station, the so-called "Despatcher" with his head telephone always on the line, so that the way station need only go in on the line and ask for the desired station. This arrangement, of course, gives considerably quicker service. With the centralised calling system, it is further necessary to place the line battery at the despatcher station.

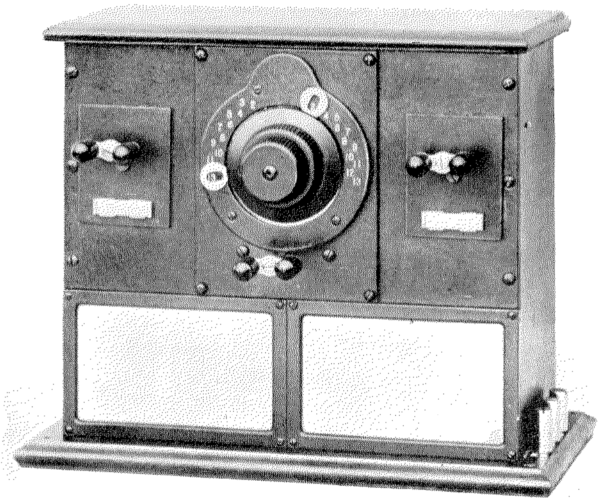

Figure 8—Special Keys for "General Call" and "Time Signal."

The non-grounded intercall system has the advantages mentioned under (5) in common with the system for centralised calling used by the State Railways in comparison with the grounded system for intercall.

The advantages here given for the non-grounded intercall system, however, must be offset against what may possibly in some respects be considered a disadvantage, i.e., that the main battery must have a higher voltage than with the other systems. There will be required, for instance, for a 50 km. long 6 mm. copper line with twenty way stations, figured from the battery station to the furthermost end of the line, 110 volts in the system for centralised calls, 192 volts in the grounded intercall system, and about 275 volts in the non-grounded intercall system.

The disadvantage of the comparatively high voltage, provided well insulated material is used for the station wiring, etc., should not be considered as of too great importance; the risk which might possibly exist for the attendants by touching the wires is very small, as the system is insulated from ground, and it is rather unlikely that a lineman would touch simultaneously both line wires. The condition mentioned regarding the voltage of the battery is in any case of minor importance in comparison with the advantages of the system which, among others, avoids the necessity for the presence of an attendant who would be required if the traffic control system were used. In cases where a person is not required for other purposes, as, for instance, attending to a manual switchboard, the system here described always has the advantage over the centralised calling system, which requires one person for attending to the despatcher station. Through the use of the intercall system, this person is not required.

The non-grounded intercall selector system here described, which makes possible a call from one station to any of a number of other stations, could therefore apparently be used to great advantage and should be used extensively, not only by railways which by the introduction of the system would be able altogether to go over to the use of the telephone instead of telegraph and thus effect a considerable saving on account of not requiring trained telegraph personnel, but also by canals and automobile transportation companies, mines, sawmills and other traffic and industrial enterprises requiring a time-saving telephone connection between various points situated at a distance from each other and wishing to save the cost of a switchboard or other central exchange with attendant personnel.

The new type of table telephone for the intercall system has for the first time been used by the above described plant for Trafikaktiebolaget Grängesberg-Oxelösund. All the equipment is manufactured by the Bell Telephone Manufacturing Company, Soc. Anon., Antwerp, with the exception of the selectors, which have hitherto been manufactured by the Western Electric Company, United States of America, but which are now manufactured by the Standard Electric in Europe.

The Selector System in Europe

In addition to the above-mentioned uses by the Swedish Railways, the system is used extensively in England and in the following other European countries:

In HOLLAND, a grounded intercall selector system for communication between eleven way stations over a 30 km. telephone cable has been supplied. The system is used for the regulation of the traffic of an electric railway.

In NORWAY, the system is used for centralised calling on the lines Oslo-Drammen and Narvik-Swedish Frontier, totalling about 125 km. and 56 selector sets.

In DENMARK, an intercall selector system is employed for the lines Copenhagen-Roskilde and Ringsted-Haestved, altogether about 70 km., 16 selector sets.

In BELGIUM, the train despatching system for centralised calling is used extensively and to great economic advantage. The Belgian State Railways had in May, 1928, 4,800 km. lines, of which the most important sections upward to 1,800 km. were equipped with the Western Electric despatching system. Including way stations, sub-stations, etc., about 1,100 selector sets were in use.

In FRANCE, train despatching systems for centralised calling as well as for intercalling are used on several of the largest railways; for instance, Paris-Lyon-Mediterranée, Chemin de Fer de l'Est, Chemin de Fer de l'Etat, Chemin de Fer du Midi and Paris-Orléans. Altogether, more than 2,600 selector sets are probably in use.

In SPAIN, the selector system is introduced or is being introduced on several of the most important lines, as, for instance, on the Madrid-Zaragoza-Alicante lines, and for the Norte and Cataluña railways—altogether, about 225 selector sets.

In PORTUGAL, the non-grounded intercall selector system is partly introduced, so far with 26 way stations.

In ITALY, in the State Railways as well as certain private railways both centralised and intercall selector systems are found, the latter systems grounded as well as non-grounded. According to information available, a total exceeding 1,300 km. railway lines are equipped with more than 300 selector sets. Of this, the State Railways own about 760 km. lines with 65 selector sets after the grounded, and 100 sets after the non-grounded intercall selector system.

In ROUMANIA, the train despatching system is used for centralised calling on, altogether, about 600 km. lines with 72 selector sets.

In CZECHOSLOVAKIA, the last mentioned system is used on about 200 km. lines with 60 selector sets, and further lines are projected.

The Editor regrets that through a last-minute printer's error, the authorship of the article, "The Brussels International Telegraph Conference," page 280, Volume VII, No. 4, *Electrical Communication,* was ascribed to Siffer Lemoine, Chief Engineer, Swedish Telegraph Administration.

This article should have appeared without credit line.

Salesmanship in Telephone Development

By R. M. REINOEHL

Commercial Engineer, International Telephone and Telegraph Corporation

SINCE 1875, the year of the invention of the telephone, the art of selling telephone service has progressed as soundly, even if not as conspicuously, as the development of the science of telephonic communication. In fact, sales efforts probably have gone through as many vicissitudes as any other phase of the telephone business.

From the first struggling days of the telephone, when the pioneer promoters carried crude portable sets about with them, forcing demonstrations upon unwilling friends in a determined attempt to obtain supporters, until the turn of the century, the telephone sales job consisted almost entirely of such haphazard promotional salesmanship. Success, during this period, depended largely on promoting the conception among those skeptical people that the telephone was no longer merely an interesting experiment, not a mere toy or scientific novelty into which it would be undignified to be found talking in more serious moments, but the source of a vast enterprise. Furthermore, the burden was upon the shoulders of those early telephone salesmen of impressing the public with the thought that the benefit to be derived from the telephone depended largely upon their appreciation of its possibilities and the aid which they would contribute toward its development.

For many years it was an uphill fight, growth remaining slow and of limited scope, in spite of all efforts that were put forth to arouse interest. For that reason the value of the service continued to be rather limited and the general public was not entirely convinced that it was worth what they were asked to pay. A great many owners of large and small business establishments were very doubtful as to whether telephone service would be of value to them. There was, for example, the case of a very prominent physician. It was believed that if he would subscribe it would greatly assist the company to induce many others to take service. He ridiculed the idea, giving for his principal reason the fact that people would get into the habit of calling him by telephone for advice which he would have to give free of charge.

Compare this attitude, if you will, with that of the present intensive period in which the physicians not only subscribe for their own service, but also arrange for secretarial service to be furnished by large private branch exchanges in order to make sure that all calls for them are properly handled during all hours of the day and night.

Then there were those who had some conception of the telephone's possibilities but were reluctant to introduce it into their establishments because it meant radical changes in their methods of doing business. Even though they admitted that these methods were often crude and frequently involved delays and inconveniences to themselves, as well as to their patrons, yet, since they were established and time-honored customs, they preferred to let the existing conditions continue.

This promotional salesmanship by a few individuals was then largely superseded by special squads making house to house campaigns, with a fair measure of success. As a natural outgrowth of this selling method, the plan was developed of having all employees participate in the contest for new subscribers. This proved to be a profitable move, for the results exceeded even the most optimistic predictions. For example, in Philadelphia during the year 1906 the net station gain exceeded the total number of stations in service when this drive began. It is interesting to note that even today this is recognized as a very successful way of selling telephones. Such periodic sales campaigns not only make large additions to the number of stations in service, but they also arouse the interest of the employees which, at times, is apt to lag. It should be noted that these efforts were expended for the purpose of increasing the number of subscribers in the system, thereby increasing the value of the service—a view which was fundamentally correct. At that time, the value of extension stations and other associated equipment, which today make the service so flexible and useful, was not appreciated. Up until the World War, growth was steady but was not secured without much difficulty, because much education of the public was still necessary.

The War, bringing other radical changes, did not fail to exert its influence on the telephone business in the United States. The demand for service by business concerns grew in leaps and bounds, and extensions of subscribers' equipment were made which up until that time had hardly been thought of. Enormous private branch exchanges, covering miles of area with private lines and many other kinds of equipment, grew over night, so to speak. Later came an unprecedented demand for residence service. Soon a condition was created which, in a way, had been hoped for but which had not been expected or desired so suddenly; the companies virtually employed their equipment up to capacity and service had to be denied to thousands of applicants, not only during the War years, but in many places for several years thereafter. If it had not been for the faith and optimism of the officials of the Bell System who were in charge before the War and who had adopted a policy of continuous and liberal expansion of plant with an eye to great future development, the War growth would have found them totally unprepared.

Selling, as commonly understood, ceased to exist. Salesmanship of the immediate post-war period consisted of restricting growth rather than encouraging it. Applicants were invariably told that there would be an indefinite delay in furnishing service. There was even a dearth of instruments and other auxiliary equipment. This was a most unfortunate situation because all of the selling momentum which had been built up during more than forty years of effort completely died down. When facilities again became available it was not easy to arouse the selling enthusiasm which had previously existed; no concern, obviously, can look forward to a prosperous future by complacently assuming that business will come of its own accord.

This inertia fortunately has been overcome, and there is no doubt that the sales spirit again pervades the personnel of the telephone companies in the United States, bringing with it new problems to be faced. During the past five years not only have new subscribers been sought, but the plan has been to make sure that from the beginning they are adequately furnished with service and equipment. In other words, a new conception has been gained of what should constitute service. For residences it is thought that the telephone equipment should be in proportion to the value of the property and the financial condition of the dweller. It is believed that luxurious homes should accordingly be equipped with such telephone service as inter-communicating systems with telephones liberally distributed. Almost any residence, it is thought, should at least have an extension telephone on the upper floor. Business houses more generally appreciate the telephone's possibilities and a very great responsibility is accepted by the companies by continually offering assistance to subscribers in the solution of their telephone problems. In the United States, Commercial Service Work, as it is called, is an important feature of both sales and customer relations activity.

The sales function of to-day is, accordingly, no longer one of merely inducing people to subscribe for service. It has become far more complex than that. The telephone salesman must be able to familiarize himself with all kinds of business to an extent sufficient to put him in a position to prescribe for the telephone needs of these various concerns. He is really selling the intangible article of "service" rather than so many telephone instruments and associated equipment.

With this broadening of the local use of the telephone, the natural result has been a great widening in the scope of use of long distance service as well. Every day there are increasing numbers of business concerns which are making selling by telephone, both local and long distance, a very definite part of their programs. "Key" towns are selected and their salesmen travel from one to another and call the prospective customers within a certain radius by telephone. Sales are made in this manner at a remarkably low cost.

It is virtually impossible to forecast just to what extent the telephone will be used in the future. Some idea of it may be gained from the fact that some department stores have recently subscribed for facilities which permit their customers for miles around to order by telephone without any toll cost to them. When the scope of usefulness is extended in this manner it is not difficult to realize that the successful telephone salesman of to-day must also be a resourceful and imaginative person. Business houses are eager to hear of any new ideas which are presented by the telephone companies, a fact which is further evidence that the telephone is now recognized as an indispensable part of our scheme of things and its vast potentialities are not nearly exhausted.

The United States of America, with one-sixth of the world's population, had until recently approximately two-thirds of the world's telephones. This is no longer true. The percentage is gradually growing downward, not because of retarding development in the United States but because of the rapid expansion which is taking place in other parts of the world; an expansion which has evolved from those early discouraging days to the present-day international scope, in which latter activities the International Telephone and Telegraph Corporation and its Associated Companies throughout the world are playing a not unimportant part. More and more countries are recognizing increasingly the benefits to be derived from the telephone development of the past fifty years, a development not only in the art of telephony but also in the art of distribution—two factors which have combined to produce the new conception of subscribers adequately equipped with telephone service and using it increasingly over an ever widening area.

Keeping pace with the rapid growth of local service throughout the world is the remarkable use of intra- and international service. Intranational service breaks down the barriers of sectionalism which, in turn, is one of the greatest factors toward national achievement. International service, as has often been said before, without doubt, will be one of the greatest instruments for creating better understanding and, consequently, promoting lasting peace among the nations of the world. This achievement has been made possible by the coöperation of those engaged in all branches of the telephone industry, and surely, in these endeavors, the art of salesmanship has not played the most inconspicuous part.

The Modern Plant of the Nippon Electric Company, Limited, at Tokyo

By A. G. JILLARD

Far Eastern Director of Manufacture

A DESCRIPTION of the plant and work of the Nippon Electric Company, Limited, would not be complete without reference to the situation at the time of the Great Earthquake[1] of September 1, 1923, and the very radical changes it brought about. At that time the plan for the ultimate development of the plant included the construction of buildings up to the property lines, and the five buildings which had been built in accordance with that plan were of reinforced concrete. Four of these buildings were three stories high, and one was partly two stories and partly three stories high. (Figure 1.) The total gross floor area in these reinforced concrete buildings was 185,750 sq. ft., and the total gross floor area of all buildings then on the compound was 293,753 sq. ft. The earthquake completely ruined the reinforced concrete buildings down to the level of the second floors, though it has been practicable to use the ground floors of these buildings, after proper repairs, until new buildings could be built. As all of the other buildings on the compound were small, and old structures marked for demolition, the earthquake resulted in a situation calling for the reconstruction of the entire plant.

Prior to the Great Earthquake, manual telephone equipment only had been used by the Department of Communications; but since fourteen of the nineteen exchanges in Tokyo and both exchanges in Yokohama were destroyed by the earthquake and fire, the Department of Communications very wisely concluded that it was a most propitious time for the adoption of an automatic system.

The Company therefore faced a situation calling not only for disposal of wreckage and the repairing of buildings, equipment, and apparatus, but also for immediate preparation for the manufacture of a complete line of automatic central office and subscribers' equipment and the rebuilding of the entire plant with a minimum of interference with production.

While this was a gigantic task fraught with difficulties and commenced under most depressing conditions, it has been handled in a manner which has brought forth much favourable comment, and the company is justified in feeling proud of what has been accomplished.

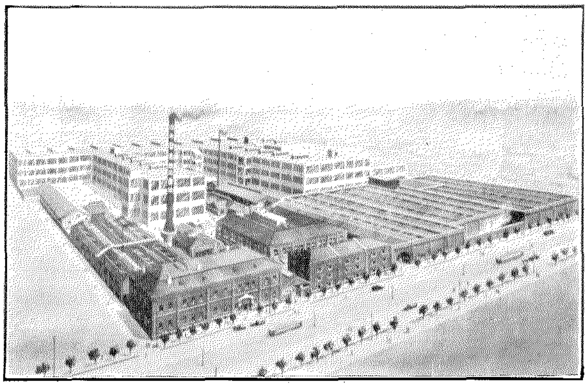

Figure 1—The Nippon Electric Company Plant at the Time of the Great Earthquake of September 1, 1923.

Demolition of the wrecked portions of the buildings and the salvaging of materials, parts, apparatus, and equipment, were started simultaneously on the seventh day after the quake, and twenty-seven days later the Manufacturing Branch began delivering fully repaired apparatus. Remains of buildings were made usable, and regular production was resumed with remarkable speed, while at the same time plans were being made for new buildings and preparation was commenced for the manufacture of automatic apparatus.

Including a two-story steel-frame warehouse in a detached compound, the Company now has more floor area than at the time of the quake and eighty percent of it is in newly constructed buildings. Fifty percent of the ultimate building plan has now been realized. (Figures 2 and 3.)

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[1] S. Inada, "Description of Damage Done by the Earthquake to Wired and Wireless Telegraph and Telephone Installations of Japan," *Electrical Communication*, Vol. III, No. 2, October, 1924.

The New Plant

After very careful study of all types of buildings throughout the earthquake zone, the Company decided against the construction of reinforced concrete buildings and adopted steel-frame construction with reinforced concrete walls, floors and roof slabs. At the same time there was developed an entirely new ultimate plan (Figure 4) in which the buildings are set back from the property lines on the sides and back of the compound, thus greatly reducing the fire hazard and permitting all building entrances, except the main entrance, to open within the Company's property instead of to the public streets. The structures are built to the property line on the front street, which is sufficiently wide to permit of this without undue hazard. (Figure 5.)

The three connecting buildings at the front of the compound are sixty feet wide and four stories high. Buildings in the parallel wings which join the front buildings are partly four and partly three stories high, being eighty feet wide on the first floors and sixty feet wide on the floors above, thus providing light courts for the illumination of the second, third, and fourth floors. Skylights in the roofs over the first floors at the bottom of the light courts provide additional illumination for the first floors. This plan gives a large proportion of first floor area which is of great importance in a country regularly visited by earthquakes, because it permits keeping all heavy loads on the ground floor.

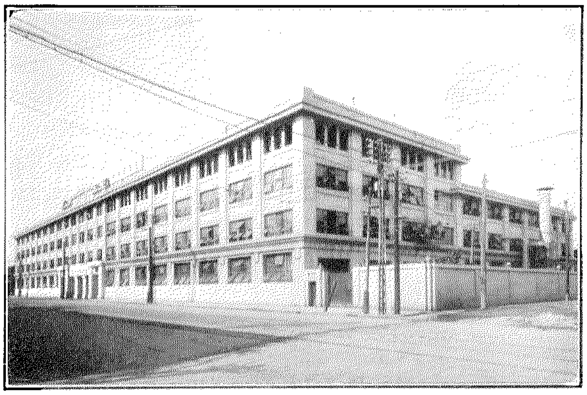


Figure 2—Some of the New Buildings, Showing the Main Entrance and the Completed Frontage on the Main Street.

As the building and floor areas are limited by Municipal Ordinance, one of the paramount aims of the designers was to utilize the entire floor area allowed while producing a group of buildings pleasing in appearance, capable of withstanding severe earthquake shock and fire exposure, and so laid out as to efficiently meet the requirements of a modern manufacturing plant.

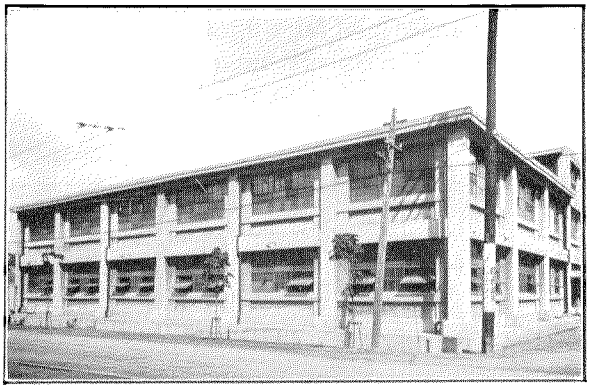


Figure 3—Warehouse in the Detached Compound.

The total gross floor area in the main buildings in the ultimate plan is 441,940 sq. ft., while that in detached buildings to be used for the storage of highly inflammable materials, automobile garage, etc., is 5,876 sq. ft.

The buildings were designed through coöperation of the architects of the Nippon Electric Company, and Japanese and American consulting engineers, all of whom had made studies of the effect of the earthquake and fire on all standard types of building construction, and were therefore especially qualified for the task set before them.

Borings to a depth of 100 ft. were made at various parts of the compound to determine the nature of the underlying strata; various test piles were driven and bearing tests were conducted with the result that reinforced concrete piles of the pedestal type were adopted. The foundations consist of individual footings under interior columns and continuous footings under outside and special columns. All foundations are of reinforced concrete and are connected by structural steel tie-beams encased in concrete.

In designing the buildings, the assumed seismic coefficient was .15, although municipal regulations require but .10, and the assumed stiffness ratio between exterior and interior bents was three to one.

The structural frame of the buildings consists of steel of rolled and built-up sections, riveted completely. All members are encased in reinforced concrete. A safety factor of four was used in designing the steel frame, and all stresses in the frame both from vertical load and earthquake shock are resisted by the structural steel. Specially designed connections of extra strength are used between columns and beams, and knee-braces are used between columns and beams in exterior bents.

In the concrete design, a safety factor of four was used, and all concrete was prepared in accordance with Professor Abram's method. Periodic tests on 6″ cube samples, seven days old, showed a consistent compressive strength of over 2000 lbs. per square inch. Concrete, except in reinforced slabs and footings, is considered only as fire-proofing for the steel; but the concrete design covered special features, including extra heavy walls on both sides of exterior columns, diagonal reinforcing at the four corners of all wall openings and diagonal reinforcing in all floor slabs around columns. In addition, the roof slabs of the light courts were made sufficiently heavy to transmit stresses between adjacent wings.

Steel window sash glazed with ¼″ wire glass is used throughout the plant, while doors are of steel and are fitted with closing devices which operate automatically in case of fire.

Modern hydrant and automatic sprinkler systems were adopted for installation throughout the plant. As severe earthquakes sometimes break the city water mains and as suppliers of electric power open their switches when there is a quake of unusual severity, outside sources cannot be depended upon for water and electric power at times of greatest need. Provision for enabling the company to operate its fire protection system efficiently without aid from outside sources, was therefore important, and to this end the system includes an artesian well and extra large storage reservoir, together with an auxiliary oil engine for operating the pumps when the power supply is cut off.

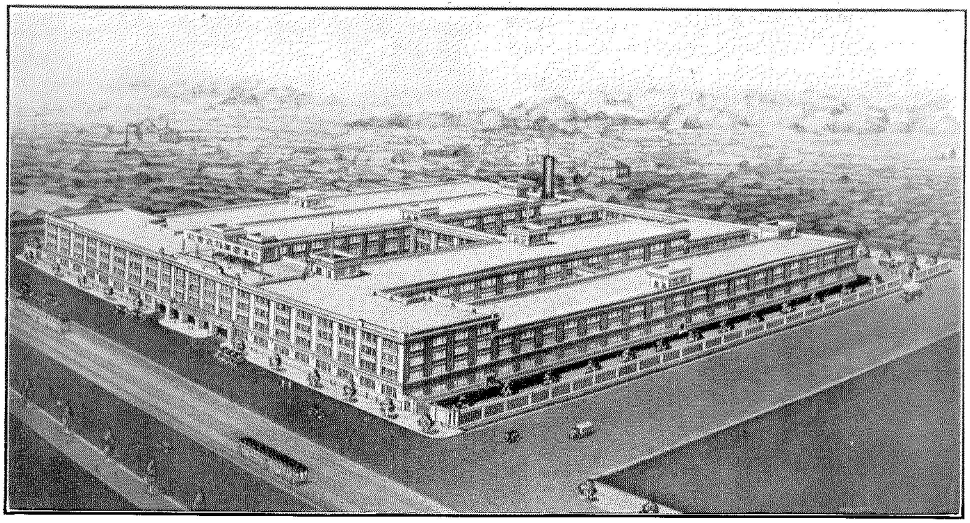
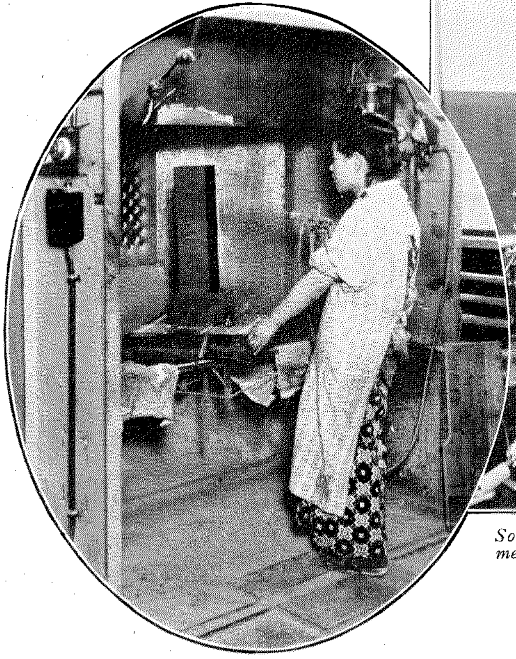


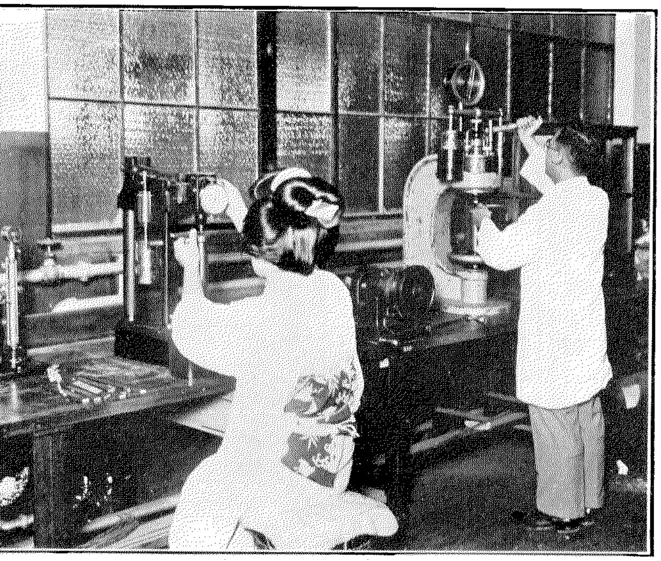
Figure 4—Architect's Drawing of the Ultimate Development of the Main Compound.

Manufactures and Equipment

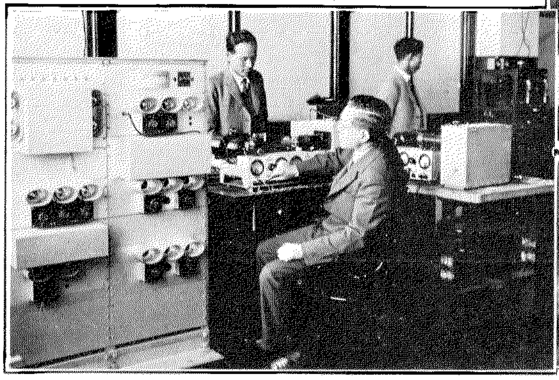
Manufactures of the Nippon Electric Company comprise central office and subscribers' equipment for both manual and step-by-step automatic telephone systems, and include telephone repeaters, loading coils, special communications appliances, electric meters, and switches.



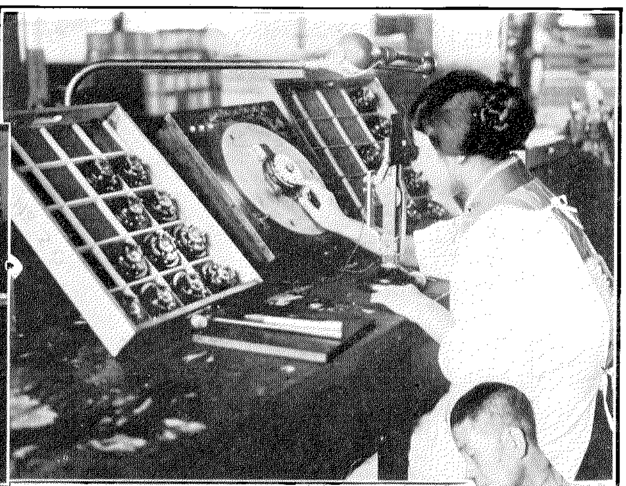
Teru Tanabe Spraying Varnish in the Wood Finishing Department



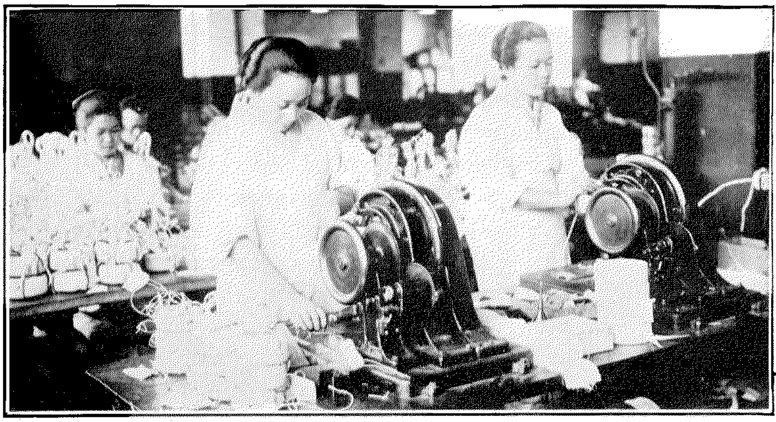
Some of the Testing Equipment in the Raw Material Inspection Department. Shigeaki Sumikawa Operating the Brinell Testing Machine and Tsuyu Takahashi Operating the Rockwell Hardness Tester



Development Laboratory. Masatsugu Kobayashi (at the left), Kinichi Ito (centre), and Yasusuke Inokuchi (right), Testing Picture Transmission Equipment



Aki Hasegawa Testing the Speed of Automatic Telephone Dials by Means of the Stroboscopic Fork



Tei Kondo and Iwano Ishioka Operating Toroidal Winding Machines in the Loading Coil Department

Kakuzo Nakagawa, an Expert Steel Treater with Twenty-eight Years of Service with the Company, Operating Electric "Hump" Furnace in the Tool Making Department

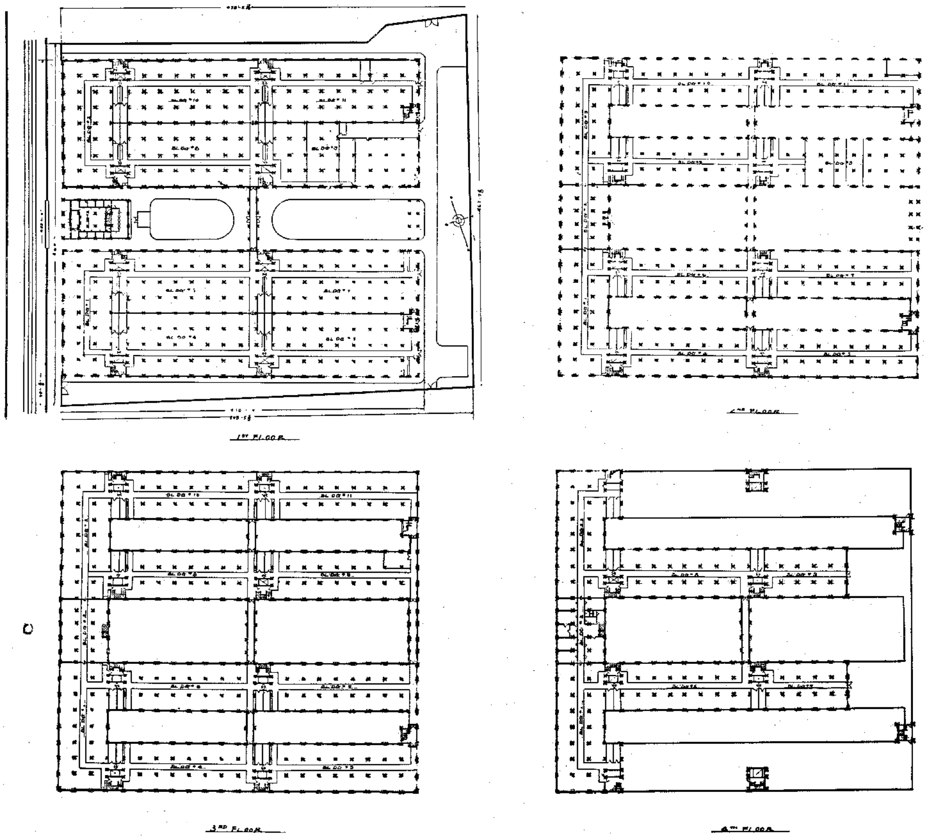


Figure 5—Floor Plans of the Buildings in the Ultimate Development of the Main Compound.

Manufacturing equipment is modern and includes screw machines, lathes, milling machines, power presses, wood working machinery, composition molding equipment, miniature lamp equipment, machinery for the manufacture of bare and insulated wire, switchboard cable, black enamelled wire, telephone cords, etc.

The Tool Making Department is manned by expert toolmakers and is equipped with modern precision machines, including a jig boring machine of extreme accuracy and a measuring microscope of most recent design. (Figures 6 and 7.) Modern tool making and heat treating practices are employed.

Inspection Methods and Engineering

A completely organized inspection department maintains a rigid inspection of raw materials, parts and completed apparatus, and is amply provided with precision testing and measuring equipment. The Company's product is carefully and minutely inspected in order to maintain the highest commercially practicable standard of quality.

A well equipped chemical laboratory is provided for analytical work and the control and supervision of chemical processes.

Studies covering the improvement of existing manufacturing methods and equipment, the development of new processes, methods, equipment, etc., and the preparation of manufacturing and material specifications are also carried on by Manufacturing Development Engineers.

The Engineering Department includes a staff of trained engineering specialists with expert knowledge of modern communications systems and equipment. In addition, information is regularly received on improvements in manufacturing and inspection developments from the Western Electric Company, Inc., and from the central organization of the Nippon Electric Company's Associated Companies.

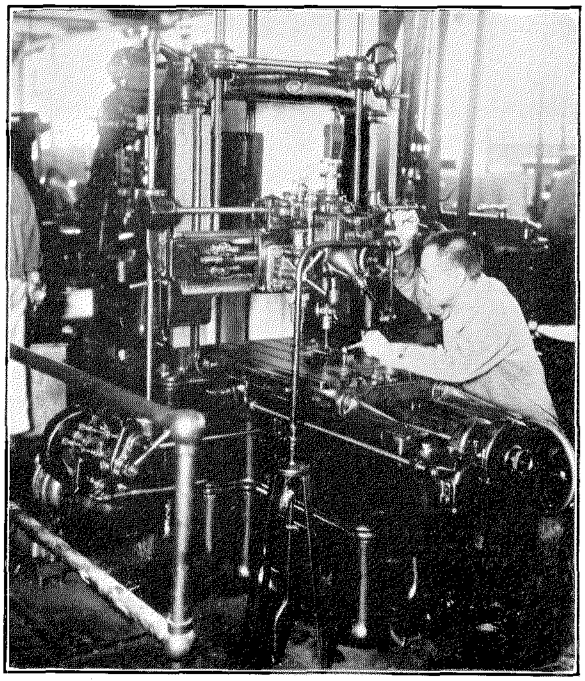


Figure 6—Koso Kitagawa Operating Direct Motor Driven Precision Jig Boring Machine in the Tool Making Department. Mr. Kitagawa Has Completed Thirty Years of Service with the Nippon Electric Company.

A check inspection of completed apparatus is carried on by the Engineering Department and is accomplished by selecting at random a percentage of the regular shop output and subjecting it to a rigid engineering inspection. This inspection is independent of the regular Manufacturing inspection, and is in the nature of an additional precautionary measure to ensure the maintenance of the high standard of excellence of which the Company is justly proud.

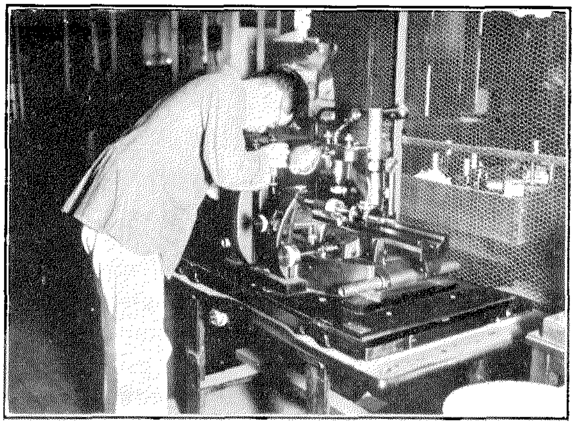
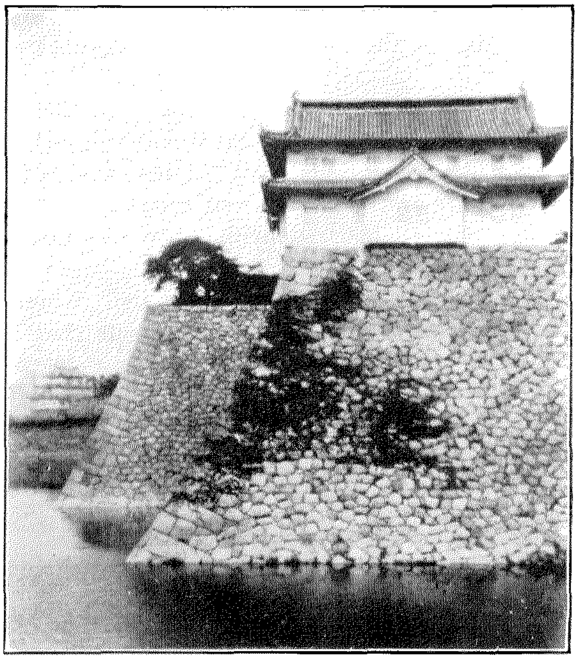


Figure 7—Yoshinori Nishida Inspecting a Thread Gauge with the Measuring Microscope in the Tool Making Department. This Microscope is Guaranteed to Measure Within .0002 m/m (.00000788") of Absolute Accuracy.



The Osaka Castle, Built in 1583. This Picture Was Sent by Wire from Osaka to Tokyo by Means of Nippon Electric Company Picture Transmission Equipment During the First Successful Demonstration in Japan of Long Distance Picture Transmission.

Phase Relations in Unbalanced Two-way Telephone Repeaters

By L. T. HINTON, A. R. A. RENDALL and C. S. WHITE
European Engineering Department, International Standard Electric Corporation

OWING to the wide use of repeaters in modern high-grade long distance telephone circuits and the importance of attaining a satisfactory repeater gain without singing, the main purpose of this paper is to investigate fundamentally the conditions obtaining in a 22-type repeater in the singing condition, to discuss the differences between singing point values obtained by different methods, and to find a means whereby the practical value of Singing Point can be derived theoretically from knowledge of the lines, networks and repeater units.

An added purpose is to describe a method of measuring phase rotation that was developed to permit a large number of measurements to be taken easily and with sufficient accuracy.

In a general discussion on "The Limitation of Gain of Two-way Telephone Repeaters by Impedance Irregularities" in the Bell System Technical Journal,[1] Crisson points out that if the gain in the singing path is greater than the loss, the power in the reflected current will increase until sustained oscillation occurs.

Another aspect of the subject is dealt with by Erikson and Mack in their paper on the "Transmission Maintenance of Telephone Systems,"[2] where on page 664, in describing the 21-test, mention is made of the effect of the phase of the return current on the value of gain at which the repeater will sing. In the same paper (Figure 16) there is shown an Impedance Unbalance Measuring Set which measures directly the unbalance of two impedances in terms of Singing Point.

Experience in the field has shown that there is often a serious discrepancy between the values of Singing Point as measured by an Impedance Unbalance Measuring Set—or as calculated from the line and network impedance curves—and the gain at which a 22-type repeater will sing when inserted between the impedances.

It has been found also that the shape of the gain-frequency characteristic of a 22-type repeater changes as the gain is increased to approach the value at which the repeater will sing. The effect of this change on the overall attenuation-frequency characteristic of a complete circuit is illustrated in the above mentioned Erikson and Mack paper (Figure 11), from which it can be deduced that at some frequencies the effective gain increases, while at others it decreases, thus giving a characteristic with a distinct periodic wave.

Theory of Singing Repeater

In order that any "feed-back" circuit such as a 22-type repeater may generate oscillations, at least as much energy must be fed back to the input as originally started the signal. There is an energy condition and a phase condition between the initial and return signals, that must be simultaneously satisfied. These conditions have been stated elsewhere[3] in dealing with the design of oscillators, but are re-stated below for convenience of reference:

(1) *Energy Condition.*

In the singing path, the total amplification must be equal to or greater than the total loss.

(2) *Phase Condition.*

Considering any one point in the singing path, the total phase rotation round the path with respect to this point, must be $2\pi N$ radians (where N is a positive integer).

Circuit Employed in Measuring Phase Rotation

The principle of the circuit is indicated in

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[1] *Bell System Technical Journal*, Vol. IV, No. 1, January, 1925.

[2] *Journal of the Institution of Electrical Engineers*, Vol. 62, No. 332, August, 1924.

[3] J. W. Horton, "Vacuum Tube Oscillators," *Bell System Technical Journal*, Vol. III, No. 3.

Figure 1, where three amplifiers, A, B, and C, are shown. These amplifiers are arranged to have a very high input impedance, and are designed to be efficient at all frequencies at which it is desired to measure the phase difference. It is convenient to make the characteristics of amplifiers A and B as nearly identical as possible in order to simplify the final calculations, but this is not essential. Amplifier C is provided, if necessary, but may be omitted if the outputs from A and B are sufficient. T is a transformer with a primary winding with two identical halves, one half being connected to the output of each amplifier, A and B, while the secondary is connected via the amplifier C, if required, to a thermocouple and milliammeter.

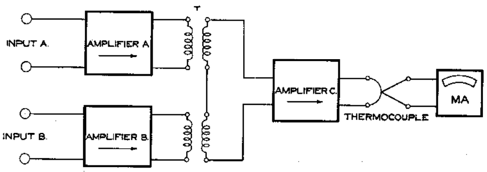


Figure 1—Circuit for Measuring Phase Difference.

The two potentials whose phase difference is required are applied to the inputs of A and B, respectively, first separately and then together. In this way three readings of current are obtained in the thermocouple circuit: (1) The current produced by the application of one unknown potential to A; (2) That produced by the application of the other unknown potential to B; (3) The current produced by the application of both unknown potentials to A and B simultaneously. From these three readings, and from a knowledge of the relative constants of amplifiers A and B, it is possible to compute the ratio of the magnitudes of the potentials applied to A and B and their difference in phase.

Theory

Let amplifier A produce a voltage amplification of n, and a phase rotation of δ, relatively to amplifier B.

Let the ratio of the two instantaneous potentials to be compared be represented by

$$\frac{E_1}{E_2}=\frac{m\ \sin\ (\theta+\alpha)}{\sin\ \theta}$$

and let E_1 and E_2 be applied to the inputs of A and B, respectively. Since the amplifier C produces the same change in both input potentials, the ratio of the two output potentials obtained in the thermocouple circuit may be represented by

$$\frac{E_1^1}{E_2^1}=\frac{n\ m\ \sin\ (\theta+\alpha+\delta)}{\sin\ \theta}$$

Let the R. M. S. value of E_1^1 be V_1

Let the R. M. S. value of E_2^1 be V_2

and let the R. M. S. value of E_1^1 and E_2^1, when combined in the output, be V_{12}.

Then, for the two potentials applied separately, if E denotes the maximum value of E_2^1,

$$V_1=\frac{n\ m\ E}{\sqrt{2}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

$$\text{and } V_2=\frac{E}{\sqrt{2}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

On applying the two potentials together, the corresponding R. M. S. value in the output measuring circuit is:

$$V_{12}=\sqrt{\frac{E^2}{2\pi}\int_o^{2\pi}\left\{\sin\ \theta+n\ m\ \sin\ (\theta+\alpha+\delta)\right\}^2 d\ \theta}$$

which, on integration over the range from $\theta=o$ to $\theta=2\pi$ gives

$$V_{12}=\frac{E}{\sqrt{2}}\sqrt{1+n^2\ m^2+2\ n\ m\ \cos\ (\alpha+\delta)}\ \ldots\ldots\ (3)$$

Dividing equation (3) by equation (1),

$$\frac{V_{12}}{V_1}=\frac{1}{n\ m}\sqrt{1+n^2\ m^2+2\ n\ m\ \cos\ (\alpha+\delta)}$$

whence

$$(\alpha+\delta)=\cos^{-1}\left[\frac{n\ m}{2}\left\{\left(\frac{V_{12}}{V_1}\right)^2-1-\frac{1}{n^2\ m^2}\right\}\right]\ \ldots\ldots\ (4)$$

Method of Measurement

In practice, amplifiers A and B are first calibrated to determine their relative constants n and δ. Inputs, equal in magnitude and phase, are applied to A and B, first separately and then together, and the corresponding readings

V_1, V_2 and V_{12} noted in the thermocouple measuring circuit.

$$\text{Then, } n = \frac{V_1}{V_2} \qquad \text{(5)}$$

$$\text{and } \theta = \cos^{-1}\left[\frac{n}{2}\left\{\left(\frac{V_{12}}{V_1}\right)^2 - 1 - \frac{1}{n^2}\right\}\right] \qquad \text{(6)}$$

If the two amplifiers are made identical, $\theta = 0°$ and $n = 1$.

When the unknown potentials have been applied, and three corresponding readings have been obtained, the ratio of the input potentials may be computed by using equations (1), (2) and (5), and the phase difference is then given by equations (4), (5) and (6).

If the two potentials are nearly 180° out of phase, the combined current in the thermocouple circuit will be very small; in this case it is convenient to reverse one of the inputs to the amplifiers, allowance therefor being made in the final calculation.

If potentials gradually changing in phase-difference are applied to the inputs of A and B, an indication of this change in phase may be observed readily by noting the variation of output-current when the two potentials are applied simultaneously; and a fairly accurate knowledge of the "in-phase" and "out-of-phase" points may be obtained by noting when the output current is a maximum and a minimum respectively.

Method of Measuring Phase Rotation Round the Singing Path of a 22-A-1 Repeater

Measurements were carried out on a 22-A-1 repeater provided with filters which had a nominal cut-off of 2,600 cycles per second.

The circuit employed is shown in Figure 2, all batteries being omitted from the drawing. Various impedances were connected to the West line and network terminals of the repeater to give known unbalances. The East line and network terminals were either respectively open and short-circuited, or, respectively, short and open-circuited.

The singing path was broken between the East bridge points of the hybrid coil and the East potentiometer, and these points were taken via switches K_1, K_2 and K_3 to the inputs of amplifiers A and B, the input to the singing path being associated with amplifier A and the output of the singing path with amplifier B.

An oscillator was bridged across the input, while a 300 ohm resistance, an input transformer, and a vacuum tube and socket were bridged across the output to terminate the bridge points of the East hybrid coil.

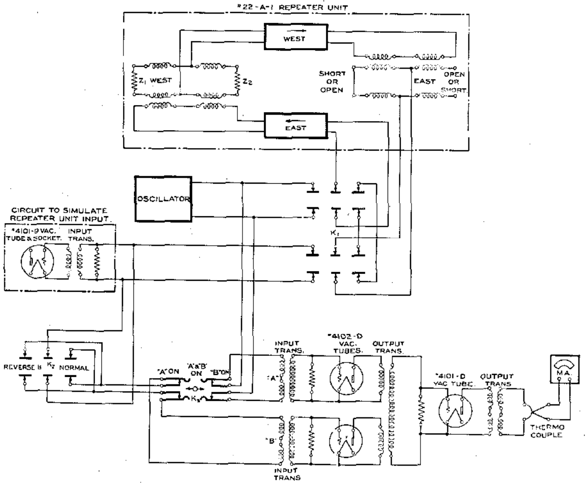


Figure 2—Circuit for Measuring Phase Rotation Round the Singing Path of a 2-wire Repeater.

The functions of the keys are as follows:

K_1 Switches the repeater through in the normal way to enable 21-tests to be made, or breaks the singing path and connects it to the phase measuring amplifiers.

K_2 Reverses the input to amplifier B to enable larger readings to be obtained on the milliammeter when the two potentials to be compared are nearly 180° out of phase.

K_3 Connects either input or output or both input and output of the singing path to their respective amplifiers.

The output of the phase measuring amplifiers was connected to the thermocouple and milliammeter.

In order to measure the phase rotation at any particular frequency the oscillator was set and switched on and the repeater was connected, by means of key K_1, to the measuring apparatus. Key K_3 was then operated to its three positions in turn, and the three corresponding currents in the thermocouple were noted. These currents were proportional to V_1, V_2 and V_{12}. Then from equation (4) above, the phase rotation, θ, was calculated.

In the measurements described below, the phase rotation at frequencies from 200 to 2,500 cycles per second was measured at intervals of 100 cycles.

For convenience, the phase rotation curves are plotted from 0° to 180°. Actually, the rotation is continuous, passing from 0° through 180° to 360° and above. A point on the curves denoted by 0° may therefore mean that the rotation is zero, or some multiple of 360°. From the point of view of utility of the curves, zero indicates an "in-phase" point, while 180° indicates an "out-of-phase" point.

Phase Rotations in a Repeater

The phase rotation experienced when a line with an irregular impedance characteristic is connected to a repeater and is balanced by a network having a smooth impedance characteristic may be shown to be made up of three components:

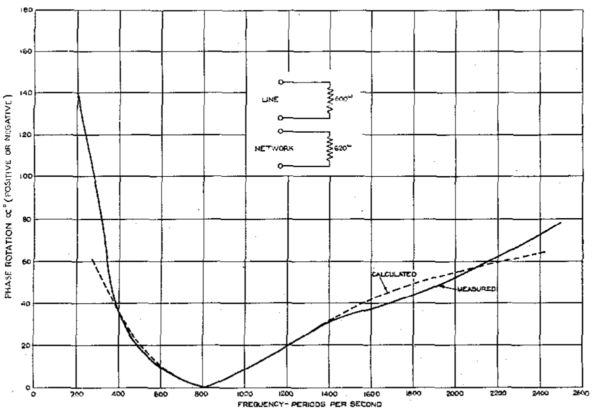


Figure 3—Phase Rotation Round the Singing Path of a 22-A-1 Repeater Without Filters. Resistance Unbalance.

(a) The rotation in the amplifiers, input transformers, and other circuit elements.
(b) The rotation due to the filters.
(c) The rotation across the hybrid coil due to the unbalance between the line and the network.

Figure 3 shows the rotation in the amplifier without any filters in circuit, the unbalance being a pure resistance. The curve has an "in-phase" point at about 800 cycles, while over the rest of the speech range no "out-of-phase" point is obtained.

Figure 4 indicates the results when the above measurement was repeated with the normal filters in circuit. This curve shows two "in-phase" points and one "out-of-phase" point. Hence, if a pure resistance line and network were used with sufficient unbalance to satisfy the power condition for singing, the unit would sing at 450 cycles, or at 2,500 cycles, or at both simultaneously. Again, if a large unbalance were located at any other frequency, singing could not possibly take place. This condition is referred to in more detail later.

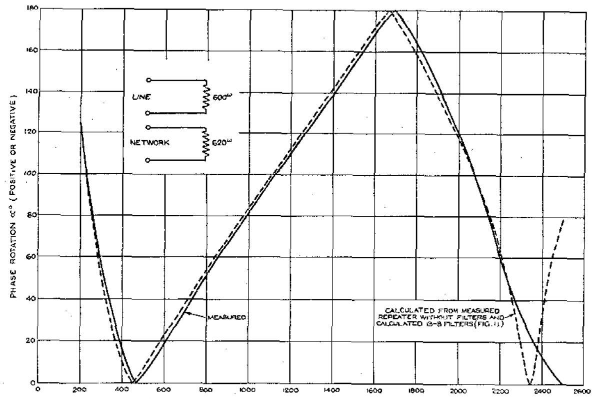


Figure 4—Phase Rotation Round the Singing Path of a 22-A-1 Repeater with Filters in Circuit. Resistance Unbalance.

Figure 5 indicates the phase rotation between the third winding and the bridge points of a hybrid coil when two impedances are connected to the line and network terminals having various moduli-ratios, $\frac{Z_2}{Z_1}$, and various angular differences $(\theta_2 - \theta_1)$.

When the above three types of rotation are present and when an artificial lump loaded line is used, the total rotation is as shown in Figure 6. In this case the resistance-component of the line impedance is as shown in Figure 7, where the network for balancing was a pure resistance of 1,600 ohms.

From Figure 6 several remarkable results can be derived. First, it will be seen that the "in-phase" points occur at somewhat closer intervals than the peaks of the resistance ripples in Figure 7, this being due to the added rotation of the amplifiers and filters of Figure 4. Next, it will be noticed that above that frequency where the resistance value of the line ceases to cross that of the network, an "in-phase" point is not obtained, and singing cannot take place.

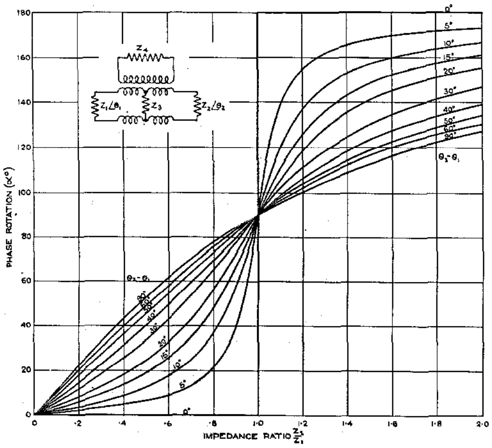


Figure 5—Calculated Phase Rotation Across a Hybrid Coil Due to Various Unbalances.

Effect of Phase Rotation with an Irregularity—i.e., an Unbalance Between Line and Network—at One Frequency Only

From the measurements on the repeater with filters in circuit, Figure 4, it appears that an "out-of-phase" point occurs at approximately 1,700 cycles, while "in-phase" points are obtained at 450 and 2,500 cycles; it is therefore to be expected that singing will not take place if a single irregularity exists at 1,700 cycles, or indeed at any frequency other than 450 and 2,500 cycles. The truth of this was verified by connecting to the line terminals a resistance of 600 ohms and to the network terminals a circuit consisting of 600 ohms in series with a circuit resonant at approximately 1,700 cycles.

The impedance (Z) of the circuit connected to the network terminals was measured (Table I). From these measurements, and a knowledge of the impedance connected to the line terminals, namely 600 ohms, the transmission loss and phase rotation across the hybrid coil due to this unbalance was calculated from the well-known expression

$$\begin{aligned}\text{Transmission Loss (Current Ratio)} &= \frac{1}{2}\,\frac{\left(1-\dfrac{Z_2}{Z_1}\right)}{\left(1+\dfrac{Z_2}{Z_1}\right)} \quad \ldots\ldots\ldots\ldots\ldots (7)\\ &= r\underline{/\alpha}\end{aligned}$$

Where Z_1 = line impedance.
and Z_2 = network impedance.

The full line curve in Figure 8 shows the phase rotation, while the broken line curve denotes the transmission loss as a current ratio.

The phase rotation round the singing path is shown in Figure 9, and in discussing these results two polings may be considered. In the case of the poling shown in Figure 9, the measured singing point was 16 Decibels at a frequency of 2,150 cycles, whereas it might have been expected that a singing point of zero would be obtained due to the bad unbalance at 1,700 cycles; but at 1,700 cycles the Phase Condition for singing was not satisfied, and therefore the high value of singing point is explained. More-

TABLE I.

Frequency cycles per second	R ohms	X ohms	Z	Frequency cycles per second	R ohms	X ohms	Z
200	600+	11.3	600 /1.0	1,500	652+	368	749 /29.4
400	600+	25.1	601 /2.4	1,600	850+	782	1,152 /42.6
600	600+	45.1	602 /4.2	1,700	2,060−	1,230	2,400 \30.9
800	600+	55.2	603 /5.3	1,800	746−	656	995 \41.5
1,000	600+	81.6	605 /7.6	2,000	616−	264	670 \23.2
1,200	600+	128.0	614 /12.0	2,200	607−	166	630 \15.3
1,400	600+	237.0	645 /21.6	2,400	605−	135	620 \12.6

over, as seen in Figure 8, the loss across the hybrid coil at 2,150 cycles is 0.088 as a current ratio, which corresponds to a singing point of 15 Decibels, which is in fairly good agreement with the observed value.

It is thus apparent that, in order that singing may take place, both the energy and the phase conditions must be satisfied simultaneously, and the value of the singing point depends on the unbalance at the hybrid coil at the particular frequency at which both these conditions are satisfied, and is independent of the unbalance at any other frequency.

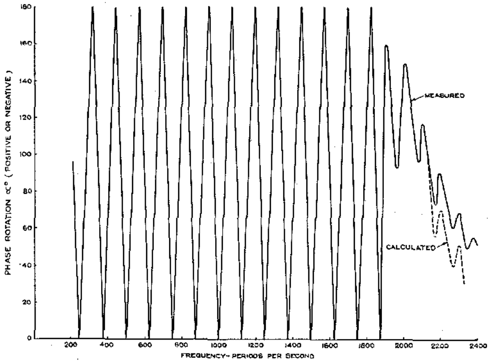


Figure 6—Phase Rotation Round the Singing Path of a 22-A-1 Repeater with Filters. Unbalance due to Artificial Lump Loaded Cable (H-177-S) and Resistance.

With the reverse poling, the curve in Figure 9 would be turned over and both conditions for singing would be satisfied at 1,700 cycles, resulting in a very low singing point.

Effect of Repeater Rotation on Repeater Gain

The effect of phase rotation round the singing path on the repeater gain has been referred to in the introduction to this paper. Figure 10 shows the gain-frequency characteristic of an older 22-type repeater, the nominal gain of which was 4.7 Decibels below the average singing point of the two pure resistance lines against their respective resistance networks. Here is seen very clearly the effect of the phase of the unbalance current passing round the singing path on the actual true gain; at frequencies where the return current is in phase with the original current the gain is increased, while at frequencies where the return current is out of phase with the original current the gain is reduced.

If, however, the nominal gain of the repeater is reduced, the return current will be reduced, and the effect on the true gain will not be so marked, i.e., the amplitude of the periodic variation of the gain characteristic will be decreased. It must be understood that it is the effective gain which the repeater gives to the circuit which is affected; the gain of each vacuum tube, of course, remains constant.

Effect of Rotation when Line Impedance Does Not Cross Network Impedance

It was noted above, in the case of an irregular lump loaded artificial line, that the phase of the return current passed through 0° and 180° at frequent intervals, so long as the impedance curve of the line crossed the impedance curve of the network (Figure 6). Above about 1,900 cycles, however, the character of the phase rotation changed, since, instead of passing through 0° and 180°, the phase of the return current oscillated about a mean value which gradually decreased until, at a frequency of 2,400 cycles, the mean value was about 50°.

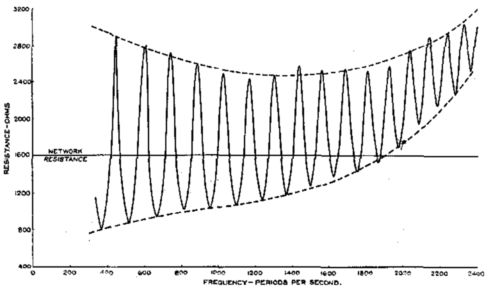


Figure 7—Resistance Component of the Impedance of an H-177-S Artificial Loaded Cable, Open Circuited at the Distant End.

The reason for this sudden change in the character of the phase rotation at 1,900 cycles is to be found in the fact mentioned above, that the resistance component of the line impedance oscillates about the network impedance of 1,600 ohms up to this frequency, i.e., at one frequency the ratio of the network impedance to the line impedance is greater than unity, while at another frequency this ratio is less than unity. Above about 1,900 cycles, however, this ratio is always less than unity. The effect of this variation in ratio is seen if it is remembered that the transmission loss across the hybrid coil is given by equation (7).

Denote the ratio $\frac{Z_2}{Z_1}$ by $(R+jX)$, where R is the resistance component and X the reactance component. Now consider R at points where $X=0$. The phase rotation across the hybrid coil is 0° when R is less than unity, and 180° when R is greater than unity. Above 1,900 cycles, however, R is never greater than unity, hence the phase rotation will never be as much as 180°. This, of course, is true only in cases where the repeater itself produces no rotation. In the actual case shown in Figure 6, the rotation due to the hybrid coil is added to that produced by the repeater unit itself.

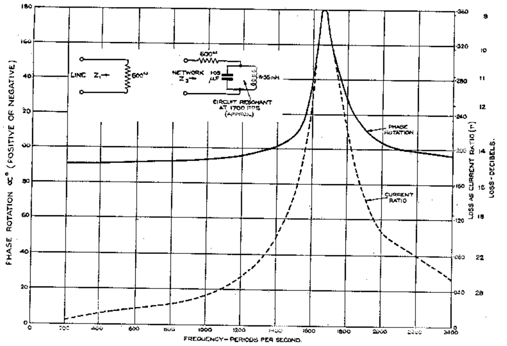


Figure 8—Calculated Phase Rotation and Loss Across a Hybrid Coil. Large Unbalance at 1,700 Cycles as Shown.

Similarity of a Number of Repeaters

Measurements on a number of repeater units with similar filters showed that with a constant resistance unbalance the units all sang at one of two frequencies, depending on the poling, and that these two frequencies were approximately the same for every unit.

False Field Singing Points and the Calculation of True Singing Point

An important result of this investigation is that it proves that a repeater will not necessarily sing at the frequency corresponding to the maximum unbalance between the line and the network, but that the frequency of singing and the actual magnitude of the Singing Point are determined solely by the conditions at the frequency at which both the Energy and Phase conditions are satisfied. It follows, therefore, that the use of a singing 2-wire repeater is unsuitable for measuring the true Singing Point of a line against its associated network, and experience in the field has shown that the error involved may be considerable. It is desirable, therefore, to consider in some detail, methods by which true Singing Point may be calculated from a knowledge of all the relevant constants of the system. In the case of a repeater without any filters, Figure 3, it is only necessary to consider the phase rotation introduced by the input transformer and associated apparatus and the hybrid coil. This rotation may be simply calculated by well-known methods. In Figure 3 the broken line curve shows the result of such a calculation in the case of the type of repeater under discussion. The agreement between theory and experiment is very close.

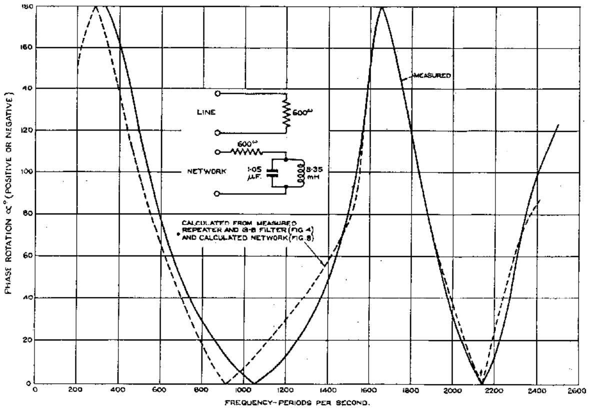


Figure 9—Phase Rotation Round the Singing Path of a 22-A-1 Repeater with Filters. Large Unbalance at 1,700 Cycles as Shown.

In computing the phase rotation across the hybrid coil for various conditions of unbalance between the line and network, it is convenient to use the curves shown in Figure 5.

Turning now to the case of a normal repeater with filters having a nominal cut-off of 2,600 cycles (Figure 4), in addition to the rotation produced by the hybrid coil, input transformers and other apparatus, the rotation produced by the two filters has to be considered. Knowledge of the constants of the filters in question enables the rotation produced to be calculated, and Figure 11 shows this rotation for both one and two filters in the singing path.

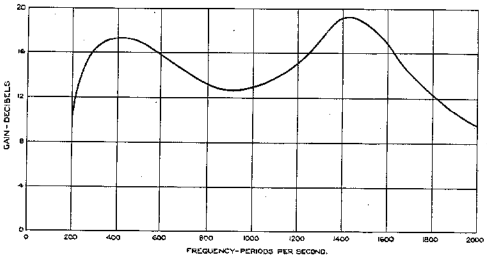


Figure 10—Gain-frequency Characteristic of a 2-wire Repeater When Near Singing Condition.

Sufficient information is now available to determine the true Singing Point under any given conditions. Consider, as an example, the condition shown in Figure 9. In this case the line impedance is a pure resistance of 600 ohms, while the network impedance is given in Table I.

Calculate in the first place, as indicated above, the phase rotation due to the repeater and its associated transformers and filters, considering the case of a pure resistance unbalance at the hybrid coil terminals, Figure 4. Determine then the rotation across the hybrid coil due to the particular unbalance (Figure 8, full line curve). Combining these two results a curve is obtained for the total rotation, Figure 9. "In-phase" points occur at approximately 1,000 cycles and 2,150 cycles. Hence, provided the energy condition is satisfied at these points, the repeater will sing at one or both of these frequencies. From the broken line curve of Figure 8, the loss across the hybrid coil as a current ratio is 0.034 at 1,000, and 0.088 at 2,150 cycles. The repeater will sing at the frequency corresponding to 0.088 current-ratio, which is the greater, i.e., at 2,150 cycles, and the Singing Point corresponding to this current ratio is 15 Decibels. In an experiment, the value obtained actually was 16 Decibels.

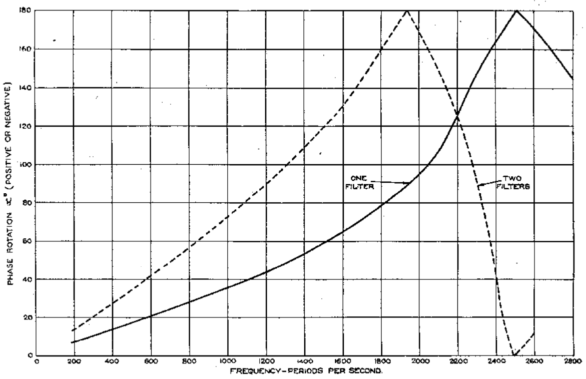


Figure 11—Calculated Phase Rotation Due to Filters Used

The Unit of Transmission and the Transmission Reference System

By G. H. GRAY

Engineering Department, International Telephone and Telegraph Corporation

VERY early in the life of the telephone industry it became evident that the handling of telephone transmission problems required the establishment of a unit of transmission in terms of which different circuits could be compared, the effects of changes in the telephone plant could be stated, the usefulness of a given circuit for transmitting conversations could be expressed, etc.

Quite naturally some of the telephone engineers selected as their unit the effect which a unit length of the then standard telephone cable (No. 19 gauge cable having a resistance of 88 ohms and a capacity of 0.054 microfarads per mile) had upon telephone conversation. This gave rise to the unit called the "mile of standard cable"—a unit which has been very widely used.

In other localities a cable having slightly different constants was used, while in still others the practice developed of expressing transmission in terms of the ratio between two currents. Furthermore, a single frequency unit referred to as the "800 cycle" mile was found useful for certain purposes, so that by 1922 the following units were in use:

English mile of standard cable.
American mile of standard cable.
800 cycle mile.

B unit (also called the Napier, Attenuation Unit or Hyp).

None of these units appeared to be universally satisfactory, particularly in view of the development of circuits having greatly improved quality and the advent of radio. This led the American Telephone and Telegraph Company to suggest the use of a purely arbitrary unit, based upon the decimal logarithm of the ratio of two amounts of power, which they called the Transmission Unit or TU. A discussion of this unit as well as the advantages and disadvantages of some of the other units mentioned is given by Mr. R. V. L. Hartley of the Bell Telephone Laboratories in a paper entitled, "The Transmission Unit," which was published in the July, 1924, issue of *Electrical Communication.*

In 1924 the International Advisory Committee on Long Distance Telephony in Europe was organized for the purpose of studying the international telephone situation in Europe and making recommendations for improvements to the various telephone administrations represented on the Committee.

Soon after its organization the International Advisory Committee took up the question of standardizing a unit of transmission. At the invitation of the Committee, the American Telephone and Telegraph Company (the sponsor of the TU) was represented at some of the meetings. Some of the countries favored the TU (based on decimal logarithms) and others the Bl unit (based on naperian logarithms). Since it was found impossible for the different countries to agree upon either of these two units the International Advisory Committee recommended that all other units be abandoned and that each country adopt one or the other of these two units. For the time being, it was agreed that all losses, gains, equivalents, etc., would be expressed in both units in the official texts of the International Advisory Committee.

It was considered important by the European Committee that the magnitudes of the fundamental units in the two systems be as nearly equal as practicable. Accordingly they defined the naperian unit so that:

$$\text{No. of units} = \tfrac{1}{2}\log_e \frac{P_1}{P_2}$$

where P_1 and P_2 are two amounts of power; and the decimal unit so that:

$$\text{No. of units} = \log_{10} \frac{P_1}{P_2}$$

It was agreed that the naperian unit should be called the "Neper" from the name Napier, the inventor of naperian logarithms, and that the decimal unit should be called the "Bel" in honor of Alexander Graham Bell. Nevertheless, in order to avoid the confusion which would inevitably result from the use of the word "Bell," it was decided to omit the final l.

It will be noted from the above that the magnitude of the Bel is ten times that of the TU as defined in Mr. Hartley's paper, to which reference has already been made. It was understood at the time the Bel was adopted as the fundamental unit that a unit having one-tenth of this magnitude, or a "decibel," would be used as the working unit. This unit is obviously of exactly the same magnitude as the TU. The arguments advanced in Mr. Hartley's paper in favor of the TU apply therefore with equal force to the decibel.

The American Telephone and Telegraph Company has decided to adhere to the decimal unit but, in the interest of standardization of terminology, has advised the International Advisory Committee that it will use the name "decibel" for its unit in place of the former designation TU. This amounts merely to a change in name, or, rather, to giving the unit a name since the abbreviation TU was adopted initially for use only until a satisfactory name could be selected for the unit. It is expected that, in the Bell System, the designation TU will gradually fall into disuse.

After carefully considering all aspects of the problem, it has seemed to the International Telephone and Telegraph Corporation that the arguments for the decimal unit outweigh those for the naperian unit. Accordingly the decimal unit has been adopted by the International as its working unit of transmission and the name decibel will be used by it for this unit. The abbreviation for decibel is expected to be db. Ten decibels will therefore be written 10 db.

As mentioned above the Bel has such a magnitude that

$$\text{No. of Bels} = \log_{10} \frac{P_1}{P_2}$$

$$\text{or No. of decibels} = 10 \log_{10} \frac{P_1}{P_2}$$

from which the following table is readily obtained:

No. of db	Approximate Power Ratio $\left(\frac{P_1}{P_2}\right)$	
	Gains	Losses
1	1.25	0.8
2	1.6	0.63
3	2.0	0.5
4	2.5	0.4
5	3.2	0.32
6	4.0	0.25
7	5.0	0.2
8	6.3	0.16
9	8.0	0.13
10	10.0	0.1
20	100.0	0.01
30	1000.0	0.001

It will be noted that the power ratio doubles (or halves) approximately every three db. In other words, if at some point, A, in a circuit the power is twice as great as at some other point B, the gain (or loss) between the two points is 3 db. Conversely, if the loss in a given part of a circuit is 6 db, we know that the power has been decreased one-fourth in that part of the circuit. Likewise a gain of 6 db indicates that the power has been increased four times.

Since

$$\text{No. of Nepers} = \log_e \frac{P_1}{P_2} = \frac{2.3026}{2} \log_{10} \frac{P_1}{P_2}$$

and

$$\text{No. of db} = 10 \log_{10} \frac{P_1}{P_2}$$

it follows that

$$\text{No. of Nepers} = \frac{2.3026}{2x10} \text{ No. of db} = 0.1151 \text{ No.}$$

of db and No. of db $= \frac{10x2}{2.3026}$ No. of Nepers = 8.686 No. of Nepers.

The following table will be found convenient for converting readily from one unit to the other:

Multiply	by	To Obtain
db	0.1151	Nepers
Nepers	8.686	db

The standardization of this new distortionless unit of transmission made desirable the standardization of a better reference system than that previously used; namely, two standard common battery sets connected through repeating coils and a variable artificial line having the unit constants of the mile of standard cable.

A discussion of a preliminary model of a new transmission reference system was given by Mr. L. J. Sivian of the Bell Telephone Laboratories in a paper entitled, "A Telephone Transmission Reference System," which was published in the October, 1924, issue of *Electrical Communication*. Additional development work on this system has since been carried out with the result that a reference system, practically distortionless in the voice frequency range, has now been adopted. A general view of the system is shown in Figure 1.

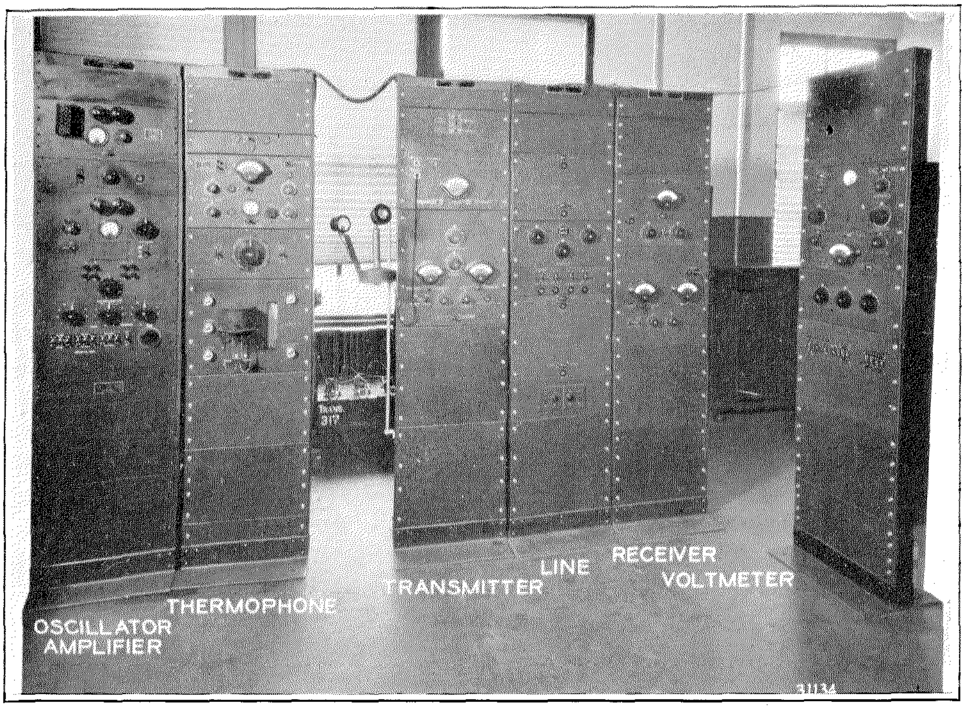


Figure 1—Master Telephone Transmission Reference System.

This Master Telephone Transmission Reference System consists essentially of three parts: a Reference Transmitter, a Reference Line and a Reference Receiver, as shown in Figure 1. The acoustic and electric performance of the system can be specified and measured in terms of definite physical quantities, and hence is reproducible. For this purpose suitable calibrating and measuring equipment, also shown in Figure 1, is associated with the system.

The Reference Transmitter consists of a condenser transmitter with four stages of amplification. It is equipped with an open wire guard which serves to keep the speaker's lips at a fixed distance from the diaphragm.

The Reference Line consists of a distortionless resistance line having a range of 101 db or a power variation of more than 10,000,000,000 to 1. The attenuation may be varied in steps of 0.2 db. By means of switches and jacks provided on the Line Bay it is possible to use the Reference Transmitter, Reference Line and Reference Receiver together, as a system, or to use each individually. This permits a ready comparison of any individual element of a commercial telephone circuit with the corresponding element of the Master System.

The Reference Receiver consists of an electrodynamic receiver and associated three stage amplifier. The receiver is of the permanent magnet type with the moving coil supported by an aluminium alloy diaphragm which is firmly clamped but not stretched.

Methods of Locating Crosstalk Faults on Loaded Cables

By K. E. LATIMER

European Engineering Department, International Standard Electric Corporation

IN THE course of maintaining loaded toll cables, it occasionally becomes necessary to locate a high crosstalk fault. Two methods for locating a resistance unbalance—the form of crosstalk fault generally encountered in practice—were described by Mr. B. Lister in 1923 in paper No. 98, Institution of British Post Office Electrical Engineers, entitled, "Maintenance Precision Testing of Main Trunk Cables." One of these is a ballistic method for use on long cables. The other is an alternating current single frequency method, for very short lengths. Both of these depend for their accuracy upon the constancy of the resistance unbalance —a condition not always fulfilled.

There are, however, two other methods by which a crosstalk fault may be located. These involve the use of variable frequency alternating current, and are less dependent than the others upon the constancy of the fault. The first of these, which has been known for many years, involves the use of a special impedance bridge and a variable frequency oscillator. The second, which has been successfully used by International Standard Electric engineers for about two years, makes use of a crosstalk set and a variable frequency oscillator.

The second method presents some advantages over the first in respect to sensitivity, convenience, and the possibility of obtaining a location from both ends of the circuit without shifting the apparatus. Both methods are described below.

Impedance Bridge Method

This method has been described in a paper on "Telephone Circuit Unbalances," by L. P. Ferris and R. G. McCurdy, in the Journal of the American Institute of Electrical Engineers, Volume XLIII, No. 12, December, 1924. For convenience, an account of the method is reproduced to show how the test may be carried out with the No. 74001-B Impedance Bridge, and for reference purposes.

The diagram of an instrument for locating resistance unbalances and other faults causing phantom to side crosstalk is shown in Figure 1. This consists of a simple bridge circuit, variable resistance and inductance being inserted in one wire of the side circuit under test for the purpose of producing in the receiver a current equal and opposite to the crosstalk current returning from the fault. Fixed inductance and resistance are inserted in the other wire of the side circuit in order to avoid the necessity of switching the variable resistance from one side of the circuit to the other, and to bring the reading of the inductometer to a convenient position on the scale. The quad should be terminated at the distant end with a crosstalk terminating set.

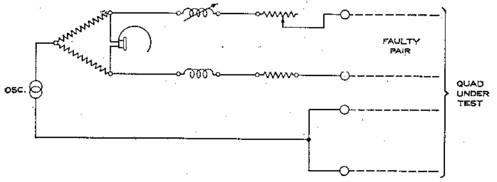


Figure 1—Diagram of Bridge for Locating Resistance Unbalances.

The procedure in making a test is similar to that in making an ordinary impedance frequency test. Readings of the resistance and inductance adjustments necessary to produce silence in the receiver are made at uniform frequency intervals, say 20 or 40 cycles, from 400 to 2,000 cycles. When these readings are plotted as functions of the frequency, the shapes of the curves obtained depend upon the type and location of the unbalance. An unbalance is indicated by periodic "humps" or peaks in the curves.

It will be seen that the tone from the oscillator is effectively applied to the phantom circuit, and travels out to the fault, at which point it is transferred to the side circuit by phantom to side crosstalk. It returns on the side circuit to the impedance bridge and enters the receiver.

The current passing through the receiver is neutralised by a second current which is produced by adjusting the resistance and inductance. Thus there will be variations in the settings of resistance and inductance necessary to balance the bridge at varying frequencies, corresponding to the time of transmission of tone to the fault on the phantom circuit plus the time of return transmission on the side circuit.

From the above consideration it may be deduced (see Appendix) that the distance to the unbalance from the testing point is given by the formula

$$x = \frac{V_1 V_2}{(V_1 + V_2) f}$$

where x is the distance from the testing end to the fault causing crosstalk, V_1 and V_2 are the velocities of the side and phantom circuits respectively, and f is the frequency interval between "humps" on the curve. This formula may be compared with the well-known formula for the location of ordinary impedance irregularities, namely,

$$x = \frac{V}{2 f}$$

where V is the velocity of the circuit under test.

To avoid separate determinations of V_1 and V_2 it is usually convenient to make a second test on a good quad with a resistance unbalance inserted at a known distance from the testing end.

The No. 74001-B and other similar Impedance Bridges of the International Standard Electric Corporation may be modified for making the above test in the manner indicated in Figure 2. It will be seen that the fixed inductance (of 30 ohms resistance) is placed on the same side of the bridge as its compensating resistance (also 30 ohms). The resistance of the inductometer is balanced out by the 100-ohm resistance. The bridge is therefore initially out of balance by about 60 ohms, and the variable resistance must be set approximately to this figure when there is zero unbalance in the line.

Crosstalk Set Method

If near end crosstalk is measured at various frequencies on two circuits between which there is some single fault causing high crosstalk, the crosstalk frequency curve will be nearly smooth.

The irregularities normally present in near end crosstalk frequency curves are due to the inter-action of many random irregularities. If, however, there is a large single crosstalk fault present, this one crosstalk predominates over all the others; and as the crosstalk due to one fault does not vary in an irregular manner with frequency, the resultant curve is practically smooth.

If there is a second fault causing high crosstalk at any point in the circuits, the crosstalk currents due to the two faults will give rise to mutual interference, i.e., the crosstalk frequency curve will exhibit a series of "humps." A brief examination of the problem will readily indicate that the frequency interval between the "humps" corresponds to the difference between the times of transmission round the two crosstalk paths. Thus, in Figure 3, the series of "humps" resulting from a crosstalk fault at A close to the measuring set and a second fault at B would correspond to the time of transmission round the path ABA; the series of "humps" resulting from a crosstalk fault at B and a second fault at C, close to the terminating set (there being no fault at A), would correspond to the difference in lags of the paths ABA and ACA, i.e., to the lag of the path BCB.

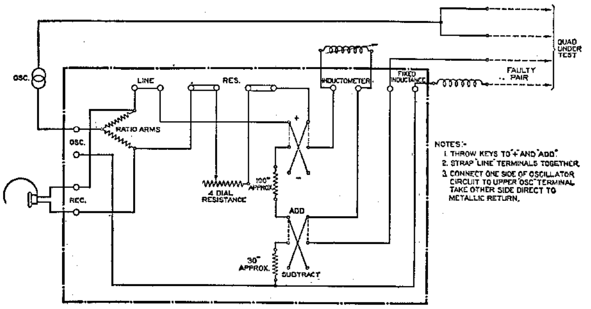

OSC.
LINE
RES.
INDUCTOMETER
FIXED INDUCTANCE
QUAD UNDER TEST
FAULTY PAIR
RATIO ARMS
OSC.
REC.
+
−
100" APPROX.
4 DIAL RESISTANCE
ADD
30" APPROX.
SUBTRACT
NOTES:-
1. THROW KEYS TO "+" AND "ADD."
2. STRAP "LINE" TERMINALS TOGETHER.
3. CONNECT ONE SIDE OF OSCILLATOR CIRCUIT TO UPPER "OSC" TERMINAL. TAKE OTHER SIDE DIRECT TO METALLIC RETURN.

Figure 2—Method of Adapting No. 74001-B Impedance Bridge for Locating Resistance Unbalances.

This at once suggests a convenient method of locating a high crosstalk fault, using the following procedure. First, additional crosstalk is introduced at the terminals of the measuring set, in any convenient manner, and to a sufficient extent to cause large "humps" on the crosstalk frequency curve. A crosstalk frequency run is then taken. The interval between the "humps" so determined gives the distance of the fault from the testing end, using the same formula as for the impedance bridge method, namely,

$$x = \frac{V_1 V_2}{(V_1 + V_2)\ f}$$

In this case, V_1 and V_2 are the velocities of the disturbing and the disturbed circuits, respectively.

It is possible to make a check test of the location of the fault by removing the added crosstalk at the measuring end, and inserting crosstalk at the terminating set. If a second crosstalk frequency run be taken, the interval between the "humps" now obtained, using the above formula, gives the location from the distant end of the circuit up to the fault. If the work has been accurately carried out, these two locations should indicate the same point. The velocities may be determined by taking a third test on two good circuits with crosstalk inserted at both ends.

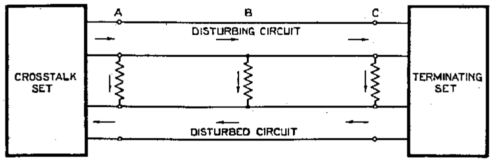


Figure 3—Diagram Showing Paths of Crosstalk Currents.

It is thus seen that it is possible to make a check location without shifting instruments about. A further advantage with this method is that no additional apparatus is required besides means of producing crosstalk and a variable frequency oscillator. The former are generally available in any place where tests are being carried out, while even if an oscillator is not available on the spot, it is usually possible to send tone over the cable from a station where such an oscillator is available.

In carrying out the test, care should be taken to use the right value of added crosstalk; if too much or too little has been added, the test will be insensitive. The right amount is indicated when sharply defined minima occur in the resulting crosstalk frequency curve. The maxima are generally less sharply defined.

The method described can be used for locating any type of near end crosstalk, that is, phantom to side, side to side, phantom to phantom, phantom to pair, or pair to pair. It cannot, however, be used for far end crosstalk, unless the velocities of the two circuits under test differ from one another, in which case the formula

$$x = \frac{V_1 V_2}{(V_1 - V_2)\ f}$$

applies. This limitation is, however, not very serious, since high far end crosstalk is usually accompanied by high near end crosstalk, and may be located as such.

A typical crosstalk frequency curve, taken for crosstalk location purposes, is shown in Figure 4. The velocities of side and phantom circuits were 14,600 and 20,400 kms. per second approximately. The distance between "humps" is seen to be 398 cycles per second.

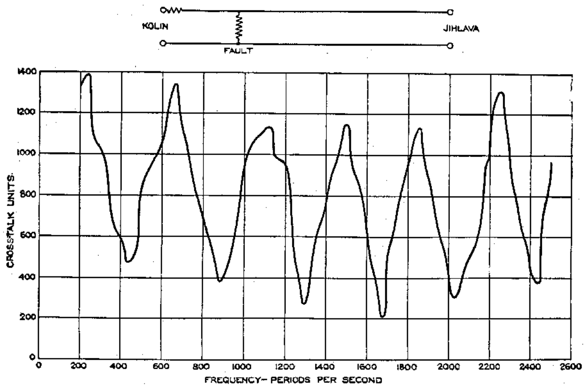


Figure 4—Specimen of Crosstalk Location Curve.

From these figures the crosstalk fault locates at a distance of 21.4 kms. from the testing end. In this particular case the fault was found to be within 0.1 km. of the position deduced from the test. As a general rule, however, such accuracy is not obtained, but the location is usually not more than one loading section distant from the fault.

The accuracy of the impedance-bridge method is of the same order.

Appendix

Both the methods described involve the determination of the small increment of frequency $(F_1 - F_2)$ necessary to increase the number of wave-lengths in a portion of the circuit under test by unity. Let

V = Velocity of transmission, assumed to be constant over the frequency range and the same for the disturbing as for the disturbed circuit.

λ_1 = Wave-length corresponding to F_1.

λ_2 = Wave-length corresponding to F_2.

x = Distance from sending end to fault, in the case of the impedance-bridge method; and the distance between the position of the fault and the point at which crosstalk is introduced, in the case of the crosstalk set method.

Then, in a length of cable x

$\frac{x}{\lambda_1}$ = Number of wave-lengths in the disturbing circuit, and also in the disturbed circuit when the frequency is F_1.

$\frac{x}{\lambda_2}$ = Number of wave-lengths in the disturbing circuit, and also in the disturbed circuit when the frequency is F_2.

If F_1 represents a frequency for which the phase relation between the outgoing and returning currents is such that a peak occurs on the crosstalk-frequency curve, it is obvious that the next peak will occur at such a frequency that the phase relations are again the same as for frequency F_1—in other words, at the frequency for which there is one additional complete wave-length in the distance 2x. Let this frequency be F_2; then,

$$\frac{2x}{\lambda_2}-\frac{2x}{\lambda_1}=1$$

But

$$\lambda_1=\frac{V}{F_1}$$

$$\lambda_2=\frac{V}{F_2}$$

$$\therefore\quad 2x\frac{F_2-F_1}{V}=1$$

or

$$x=\frac{V}{2f}$$

where

$$f=F_2-F_1$$

If the velocities of the two circuits are different, the same formula may be used, provided that the velocity V is that which gives the same total time-lag as that corresponding to the actual velocities V_1 and V_2.

The time-lag on the disturbing circuit will be $\frac{x}{V_1}$, and on the disturbed circuit $\frac{x}{V_2}$. Hence, V is determined by the following equation:

$$\frac{2x}{V}=\frac{x}{V_1}+\frac{x}{V_2}$$

thus,

$$V=\frac{2\,V_1\,V_2}{V_1+V_2}$$

And substituting in the above equation,

$$x=\frac{V_1\,V_2}{(V_1+V_2)\,f}$$

The "Solid Back" Carbon Button Telephone Transmitter

By L. C. POCOCK

Engineering Department, Standard Telephones and Cables, Ltd.

AS EVERY telephone engineer is aware, fully dimensioned drawings are not enough for the successful building of communication apparatus. In addition to drawings, there must be a description of materials and processes used; and before success is achieved there must be a fund of experience, precise understanding of the exact requirements of the apparatus, knowledge of the permissible variations in the material and the reactions of these variations on the behaviour of the completed article. Probably experience and knowledge are nowhere more essential than in transmitter manufacture, partly because of the extraordinary delicacy and sensitivity of the instrument, and partly because of the complex conditions to be satisfied.

The extremely small movements of a transmitter diaphragm under normal speech conditions and the large amplification factor are not generally appreciated. In the case of the well-known "solid back" transmitter, the diaphragm movement may be of the order of 10^{-5} cms. (.0001 cm. or .00004 inches). This extremely small amplitude is comparable with the changes of dimensions that occur in the instrument through expansion due to temperature variations of one or two degrees centigrade. Dimensional changes of the same magnitude may be produced also by elastic deflection under loads of a few grammes. The minute movements of the diaphragm, however, result in an electrical output of the order of 10 milliwatts, which may be about one thousand times as great as the speech power directed into the transmitter. That such an amplifier exhibits a certain amount of instability, and that it cannot be built properly without skill and experience is, therefore, not surprising.

The most obvious requirement in a transmitter is efficiency. Mechanical faults, badly fitting parts, errors in adjustment, and variation in quality of material, all reduce efficiency. Such faults may be very difficult to detect and may be guarded against best by rigid inspection of parts and processes at all stages of manufacture by men who appreciate the fact that they are concerned with making an instrument operating with movements smaller than ordinary gauges will measure.

Ranking with efficiency in importance for effective speech communication is quality, or freedom from excessive distortion. The faults that have been mentioned as adversely affecting efficiency, generally also affect quality, so that a mechanically poor transmitter may often be defective both in efficiency and in quality.

Whilst efficiency depends to a considerable extent on the accuracy with which the structure is built, it depends also upon the characteristics of the granular carbon. An efficiency range of at least 10 decibels ($b=1.15$) can be covered by using different grades of granular carbon; and one of the chief problems to be dealt with is the selection and uniform preparation of carbon that will most suitably meet all the requirements of the completed instrument. The most suitable, however, is generally not the most efficient for there are many other requirements to be met, such as resistance, freedom from "burning," microphonic characteristics, tendency to pack, and durability or freedom from aging effects. These depend mainly upon the physical properties of the carbon, though the effects are complicated and may be masked by the mechanical structure of the transmitter.

The resistance should be uniform and stable; it should not rise during any quiescent period to a value such as to prevent proper functioning of the signalling relays at the central office, or to reduce the receiving efficiency of the subscriber's set. "Burning," which causes sputtering or frying noises, while inherent in carbon, must be kept below the trouble point. Since burning tends to increase with age, it is a characteristic that must be studied, especially in connection with "aging" effects, or variations during the life of the transmitter.

A transmitter is said to be over-microphonic when its efficiency characteristic rises too rapidly as the load (impressed sound) increases from very weak values. Correspondingly, the efficiency of such an instrument falls rapidly as the load increases beyond normal intensity. Since speech intensity varies greatly among consonants and vowels, the more variable the efficiency of the transmitter, the poorer the quality.

"Packing" is caused, as the name implies, by packing of the carbon granules to the point where the resistance variation necessary to the proper functioning of the instrument no longer occurs.

It will be appreciated readily that with so many diverse properties depending upon the quality of carbon employed, the utmost care is essential in its manufacture. Western Electric carbon, which is used by the International Standard Electric Corporation, is made in several grades for different purposes, the grades differing not only in the size of the granules, but also in their microphonic and resistance characteristics.

The raw material from which the carbon is produced is a uniform, high quality anthracite which is picked over lump by lump by experts; the subsequent crushings, roastings, washings, and sievings are varied to secure maximum sensitivity with the particular combination of resistance and freedom from burning necessary in any particular kind of transmitter. Samples from each lot of carbon are subjected to physical tests and finally, before the lot is accepted, fifteen transmitters are assembled with specially selected parts, and filled with sample carbon. The transmitters are searchingly tested for characteristics such as efficiency, burning and resistance; and any failure to show the expected properties is followed by the rejection of the whole of that particular lot of carbon.

The policy of Standard Telephones and Cables, Ltd., is to supply only highly efficient and closely uniform instruments and it is, therefore, scarcely possible to exaggerate the importance of adherence to rigid inspection requirements for the granular carbon used in transmitter manufacture. For example, even with the manufacturing processes controlled as carefully as possible, the variations occurring in the finished material are so wide as to call for frequent rejections of lots of carbon, or for the selection of different lots for different purposes, although made by the same process. Tabulated below are the results of tests on twelve different lots, all manufactured by the same process, but selected to cover a wide range of different properties:

Sample	Allowance		Resistance in ohms, while talking
	db.	b.	
A	−0.25	−0.029	52
B	−0.25	−0.029	51
C	−0.50	−0.058	50
D	−0.75	−0.086	58
E	−0.90	−0.103	57
F	−1.1	−0.126	49
G	−1.1	−0.126	44
H	−1.1	−0.126	37
I	−1.4	−0.161	49
J	−1.6	−0.184	33
K	−1.7	−0.198	40
L	−2.1	−0.241	45

These tests were made with about fifty milliamperes flowing through the transmitter.

The indiscriminate use of these varieties of carbon for ordinary common battery transmitters would lead to endless difficulties: some of the lower resistance carbons would produce transmitters of low efficiency, but, worse still, the high efficiency, high resistance carbons would develop burning after comparatively short use.

Carbon electrodes for common battery transmitters, while not quite as important as the granular carbon, are manufactured with the same care as the latter, including the making of similar tests on sample transmitters.

The assembly of the microphonic button, and its assembly and adjustment in the transmitter, offer many opportunities for serious errors. It has been found advisable to adopt a number of devices to make the various assembly operations fool-proof; in fact, nearly all tightening up and clamping operations are carried out under conditions controlling the degree of tightness used.

The testing of the finished transmitter is carried out by trained assistants whose function it is to compare every transmitter individually by means of a speech test with a standard transmitter in a representative telephone circuit. The instruments to be tested, and the standard, are mounted side by side and spoken into alternately, while a second observer at the other end of the circuit determines the difference in efficiency and quality. The successful application of this very practical test depends upon the strict maintenance of the efficiency of the standard instruments at a constant level, and consequently a group of master standards carefully built and frequently compared with each other under laboratory conditions must be maintained. The work involved in maintaining standards for use in the inspection departments is considerable, but is well justified by the advantage of being in a position to know with certainty whether the manufactured apparatus is satisfactory or not, so that in the latter case investigation can be started promptly to trace the cause of the trouble. Furthermore, effective investigation is hampered, or rendered practically impossible, if thoroughly trustworthy standards are not available.

Transmitters passing the first shop inspection are sampled twice by separate inspection departments for much more complete and thorough tests, and finally samples may be taken for life tests.

Notwithstanding all precautions, certain variations in the efficiency of the manufactured product occur, as illustrated in Figure 1, which show the average efficiency of samples taken from successive deliveries. Such fluctuations are caused chiefly by variations within the permitted limits of some of the parts, but may be due also to a certain extent to variations in the carbon quality. Using a given grade of carbon and selected parts specially fitted, it is quite possible to make transmitters equal to each other within 1 db. (b=0.115) or less, but such close uniformity has proved to be impossible under mass production conditions.

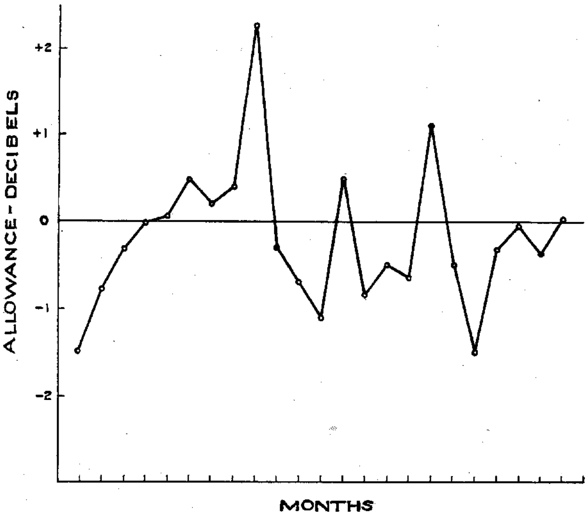


Figure 1—Averages of Tests on 20 Representative Transmitters Taken From Deliveries Each Month.

While considerable development work has been done on this type of instrument, it is a fact that comparatively few modifications have been introduced in the solid back carbon button transmitter in countries where it has been standardized. One reason is that, while not ideal, the instrument is the best that has thus far been proposed for commercial use. Furthermore, the adoption of a radically new design, a modification of the present type, or the use of carbon from new sources of supply, in the opinion of those qualified to judge, involves a real danger of encountering serious trouble through low efficiency, large percentage of instruments liable to pack, or what is most serious, development of burning after one or two years of life. Even with artificial life tests, it is extremely difficult to obtain warning of the faults that may arise in the field. A transmitter should have a reasonably long life, and failure after one or two years is a heavy loss. Furthermore, a fair trial necessitates placing a considerable number of instruments in service and some years may elapse before the results of a departure from ordinary practice can be evaluated.

The transmitter, converting as it does the sound power input into electrical power which is transmitted over the line to the receiver, is one of the most important pieces of apparatus in the telephone system. It must be efficient, high in quality, and relatively constant in its characteristics, even when subjected to the rough usage frequently encountered under service conditions. When manufactured in quantity, these requirements can be met only by close attention to detail both in design and in manufacture, by careful inspection and testing, especially of the carbon itself, and, finally, by comparison of the commercial product with reliable transmitter standards.

The Creed High Speed Morse Printing Telegraph System

By F. G. CREED

Chairman, Creed Company, Limited

AT THE end of the nineteenth century, seventy years or more after the invention of the electric telegraph, but little progress had been made in the development of Printing Telegraphs. The position in Europe at about that time was that the Hughes, the Stock Ticker and the Baudot Systems were in use on some of the more important circuits in several countries, but the Morse Telegraph was by far the most extensively used System. In Great Britain, the Baudot and Hughes were employed principally for Continental circuits; but the Stock Ticker, for the distribution of market and other news, could be found in all the large cities of the Kingdom. The busiest commercial circuits, and all the more important news circuits of the Post Office, were operated by means of the Wheatstone System, and in addition, a great many Morse duplex and Morse quadruplex systems were employed in handling traffic between larger towns.

The provincial newspapers were nearly all served through the British Post Office by a special organisation based on the Wheatstone System. News gathered in London by the Press Agencies was dealt with in a special section of the Central Telegraph Office, where it was first punched up on the Wheatstone tape by means of a special arrangement of Wheatstone Perforators which enabled a single operator to perforate simultaneously any number of tapes from one to sixteen. The tapes thus prepared were then run through groups of transmitters by means of which the news was distributed simultaneously to provincial towns, where it was written up by hand and delivered by messengers to the newspapers entitled to receive it. In some cases as many as one hundred newspapers in fifty or more towns would receive a news item thus distributed from the common centre.

For the reception of this news at the provincial stations, a staff of nine men (one key clerk and eight writers) was usually provided, the duty of the key clerk being to supervise the line and terminal apparatus, to distribute the Wheatstone tape to the writers, and to ask for and obtain repetitions. Usually several stations would be connected to one line, called a "YQ" circuit, and the normal speed of working was 200 words or more per minute.

In addition to the Post Office News Services a number of the provincial newspapers had private lines to their London Offices in Fleet Street, and the busier of these lines were generally worked by Wheatstone—some of them at very high speeds. A Glasgow newspaper for many years maintained a normal speed of 400 words per minute, although the traffic load seldom exceeded 6,000 words per hour, or an average rate of 100 words per minute. Such high speeds led to an excessive number of RQ's (repeats), and probably did more than anything else to prevent wider use of the Wheatstone System, and to encourage the development of the less speedy but more efficiently operated Printing Telegraph Systems since introduced.

The Early Keyboard Perforator

In 1897 the writer came to England with the object of developing a Keyboard Perforator for use in connection with the Wheatstone System. He had had some experience in telegraphy in the Western Union, and the Central and South American Telegraph Companies, and hoped, by the introduction of a Keyboard Perforator, to save much of the labour involved in the preparation of the Wheatstone tape. After years of hard work and financial stringency, he, and later, Mr. Gell, produced a satisfactory machine.

The first Creed Perforator was not unnaturally of a somewhat crude, if efficient, design. It was operated by compressed air. A keyboard was provided, coöperating with a group of punches, an air-operated hammer and distance pieces adapted to be inserted between the hammer and the punches by a selecting mechanism under the control of the keys, and an air-operated feed mechanism, Figure 1. This instrument could perforate and feed from one to four tapes at a time, and was on the whole a satisfactory machine, its chief drawbacks being the noise produced, and the necessity of providing air-compressing plant.

The Early Receiving Reperforator

Attention was next directed to the receiving end of the Wheatstone circuit, with the object of providing an automatic means of printing the messages in Roman characters as fast as they were received over the line. This was not an easy task. On consideration of the problem of printing from the Morse code, it is evident that the principal difficulty lies in the fact that the Morse letters are of unequal length, and that the shortest and most frequent letter "e" is, in point of time, very short indeed. For instance, when operating at a speed of only 100 words per minute, the letter "e," together with its following space signal, only occupies one-twentieth of a second in transmission. No mechanism existed at that time, nor does it exist at present, which enables a type to be selected from a group, printed on a tape or page, and everything returned to normal in such a short space of time.

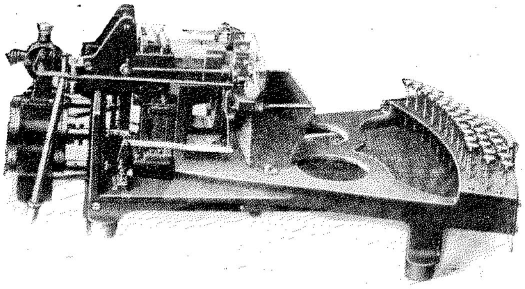


Figure 1—Early Keyboard Perforator.

The problem of direct printing from Morse signals *at high speed* has not yet been solved. Confronted with this difficulty, the problem was attacked in another way. If the dots and dashes as represented by perforations in the Wheatstone tape, could be reproduced in the same form at the receiving end of the line, the reperforated tape thus received could perhaps be used to actuate a typewriter or similar mechanism operating at a speed lower than that of the line. Such a solution would involve the invention of two machines instead of one, and would cost a great deal of time and expense, but it seemed to be the only way out of the difficulty, and so the development was undertaken along these lines.

After a year or more, a Receiving Perforator (Figure 2) was finally developed which was sufficiently fast and reliable for most commercial purposes. In this instrument compressed air was again employed. A Standard Post Office Line Relay was used to control a Power Relay in a local circuit. The Power Relay in turn moved the tiny piston valve of a small compressed air engine. The reciprocations of this little engine, under the control of the Line Relay, actuated a pair of punches which perforated the corresponding holes in a blank tape drawn through the machine by means of a feed wheel mounted on a frictionally-driven spindle. A wedge inserted at the moment of punching, between the teeth of a saw-tooth wheel on the feed spindle, brought the tape into the correct position and held it there during the operation of punching, so that the holes made by the punches always came directly opposite to the corresponding feed holes on the tape. This simple method of correction for speed variation

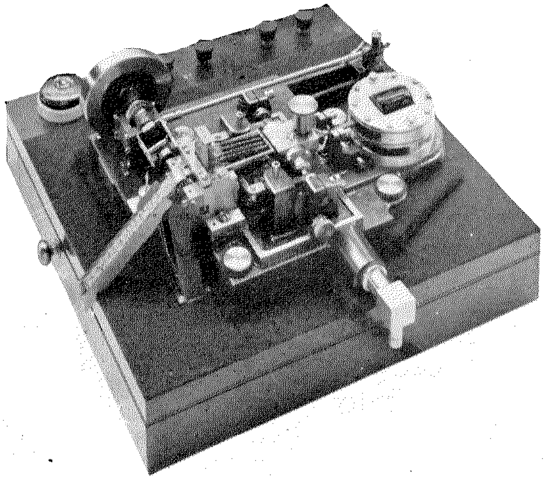


Figure 2—Air Type-Reperforator.

between the transmitter and receiver proved very satisfactory, and was capable of dealing with speed differences as between transmitter and receiver of not less than 15% up or down. Operating speeds up to 150 words per minute were quickly obtained, and the commercial exploitation of the apparatus was begun. It was soon evident, however, that although the machine was able to do as much work as several operators, it would have very little vogue because there were comparatively few cases where such reperforating, apart from any printing operation, was necessary; but at last an application was found for the Reperforator in Manchester, where a certain class of news was received daily for retransmission to Northern towns.

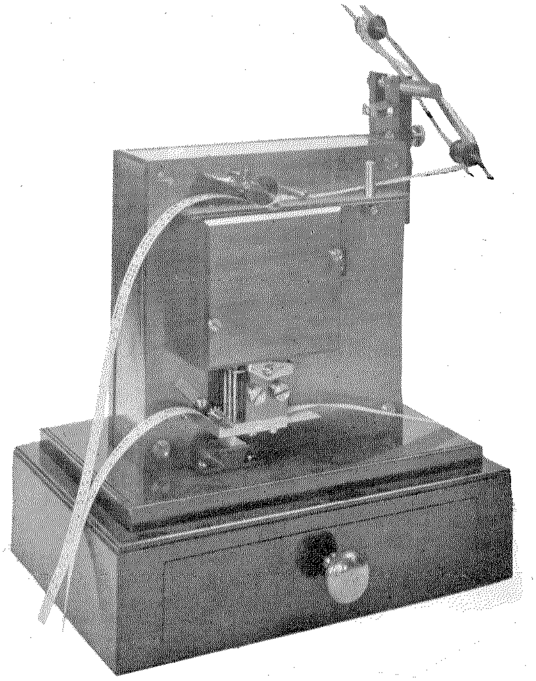


Figure 3—The Cable Translator.

The usual procedure was to provide a staff of nine operators, one to supervise the receiver, and the other eight to write the messages from the Wheatstone tape, at the same time making copies for local newspapers. Another group of eight operators then perforated the messages for retransmission over the YQ lines to Glasgow, Edinburgh and other cities. The introduction of the Receiving Reperforator made it unnecessary to employ these eight operators for reperforating purposes, and thus secured important savings in time and operating costs.

Another field for the apparatus was found at Fredericia in Denmark, where messages passing over the Great Northern Telegraph Company's lines between England, Russia and Scandinavian countries were perforated for retransmission. No other applications could be found for the Reperforator alone, except at the cable station of the Anglo-American Telegraph Company on Valencia Island. At this Station messages were received by Wheatstone from London and Liverpool, and then reperforated in cable code for transmission over the submarine cables. Before the Receiving Reperforator could be introduced at this station, it was necessary to devise some means of causing the Wheatstone Morse signals to perforate Cable Code, or of causing the perforated Wheatstone tape from the Receiving Reperforator to control another machine in which a Cable Code tape would be perforated.

The latter alternative was adopted, and a satisfactory machine was designed for the purpose. This was known as a Cable Translator, Figure 3. By the use of the Receiving Perforator and the Cable Translator, it was found possible, under the control of one Transmitter in London or Liverpool, to produce enough Cable Code tape at Valencia to keep three Trans-Atlantic cables fully occupied. Some years later, the Eastern Telegraph Company employed the

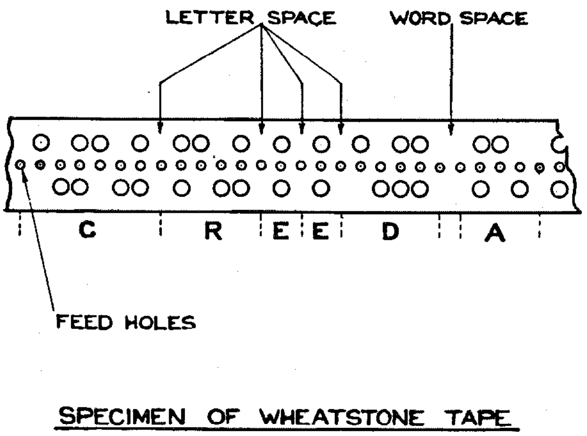


Figure 4—Specimen of Wheatstone Tape.

Receiving Reperforator for automatic retransmission at certain intermediate stations between England and South Africa, Australia, South America and the Far East, but at the time the Valencia Station was equipped in 1900/1904 there seemed to be no further applications for the apparatus, and the writer was driven, by the necessities of the case, to invent a Printer in order to complete his Morse Printing Telegraph System, and thereby to open the doors of the whole telegraph world to his inventions.

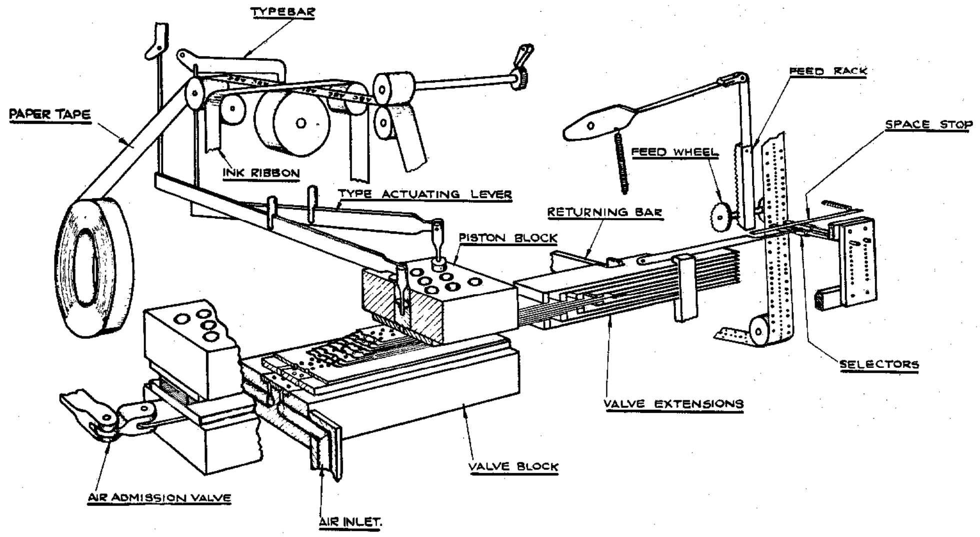


Figure 5—Principle of Printer Selecting Mechanism.

The Early Morse Printer

The invention of a machine to print from the Wheatstone tape was by no means an easy task. Obviously it was necessary to provide a sufficient number of selective elements to deal with the longest or shortest character at one operation. The longest character, the figure 0, contains eleven spaces along the tape. The shortest character contains two spaces, and in addition, there is the space itself, so that it was essential to be able to deal with characters containing any number of spaces from one to eleven. These lengths of tape must not only be "read" but also "fed." It would be easy to read any particular character provided that, like the figure "0" or the apostrophe, it filled out the whole eleven spaces; but when several short characters, as, for instance, the letters of the word "the," all came within the space occupied by the selective group, how were the selectors in that group to know where each letter began and ended, and how could they deal with only one letter at a time, and pay no attention, until the right moment arrived, to the letters following? The solution of the problem of "reading" was to be found in the "feed." If means could be found to feed forward only one letter at a time, and no more, it might be hoped by the same mechanism to find a means of "reading" that letter, and of shutting out the unwanted residue. The solution, when found, was so simple that it is surprising someone had not stumbled upon it before. The secret lay in the fact that while the holes representing dots and dashes in the Wheatstone tape may be perforated on either or both sides of the central row of feed holes, there is always at least one such perforation opposite each feed hole throughout the length of any particular letter; and the double blank, which is a feed hole perforation with blank tape on both sides of it, only occurs when a space is indicated, as in Figure 4.

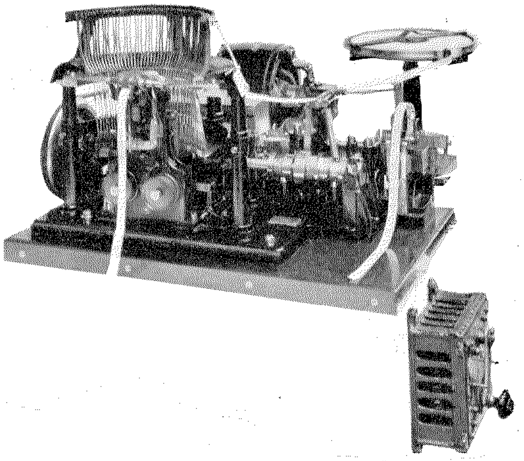


Figure 6—Creed Air Type-Printer.

Having observed this, it was only necessary for the Inventor to provide selective mechanism of a kind in which any selector, entering a hole in a tape, pushed a stop out of the track of a feed bar. The selectors being arranged in pairs, either one or both of each pair would go through the tape for every part of a letter, and would push the space stop out of position, and at the end of the letter the double blank of the space would prevent both the selectors from acting, so that the corresponding space stop would remain in position, and limit the exploring movement of the spacebar, (Figure 5).

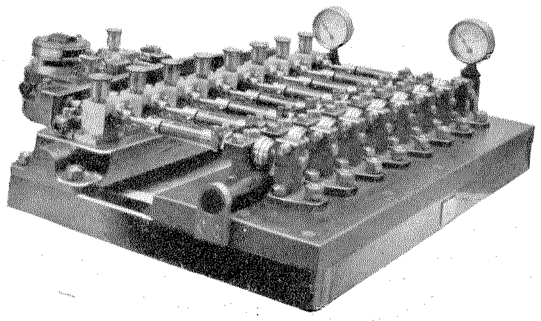


Figure 7—Creed Wireless Key (250 KW).

When this means of determining the length of a letter on the tape had been discovered, it was comparatively easy to develop a feed mechanism that would feed forward the letter being dealt with, and that would bring the next letter up into position to be read at the next operation, and also to provide a shutter mechanism that would render inoperative selectors which might be dealing with perforations beyond the space occupied by the letter being translated. It was afterwards found that the use of a shutter was unnecessary, as the effect of the unwanted combinations could be eliminated by cutting away the corresponding parts of the type selecting combs which were set up by the selectors.

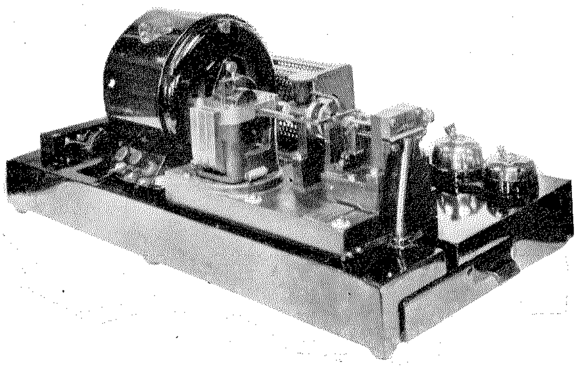


Figure 8—Morse Reperforator.

Although a solution in principle had now been found, the task remained of developing a satisfactory Printer. One of the first problems was to decide what kind of printing mechanism should be used; whether to cause the type-operated mechanism to work the keys of a standard typewriter, or to make a special printing mechanism for the purpose. It was at first intended to use a standard typewriter, but finally a special printing mechanism was developed, in which the primary selectors admitted compressed air to little cylinders containing pistons, each of which, when operated, caused the type to strike the paper through a typewriter ribbon. This was found to be an advantageous arrangement, because the little pistons could move any convenient distance, and thus follow the type-bar home, whereas the common striking bar employed by other inventors for operating the keys of a typewriter called for great accuracy in the alignment of the key levers and associated trip-bars.

In the earlier models of this Printer, the compressed air was supplied by the compressor used for the Reperforator, the pressure being regulated by a specially designed reducing valve. Later, however, a small compressor unit was introduced on the Printer itself, actuated by an eccentric on the main shaft (Figure 6). This eccentric was so set that the puff of air was delivered at the correct moment to operate the small piston after its selection. This resulted in considerable simplification of the Printer mechanism, and a reduction in the size of the compressing plant.

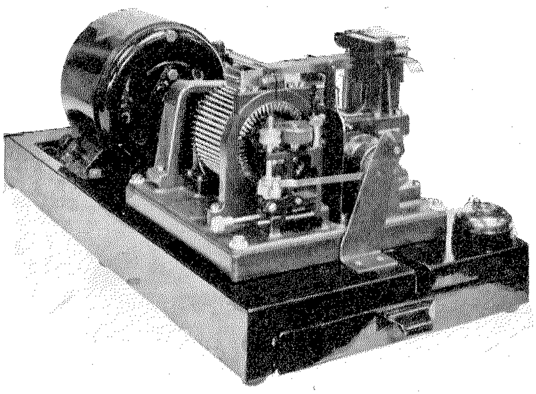


Figure 9—Morse Printer.

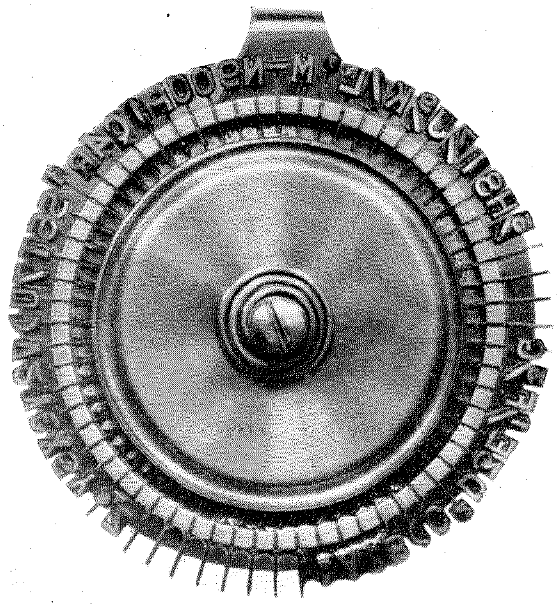


Figure 10—Printer Typehead.

The Reperforator and Printer remained more or less in this form from 1914 until 1919, when it was again possible to devote attention to development. In the meantime, it was found that the Reperforator could be adapted to the control of Radio Stations using Arc transmission, which were very popular at that time. The punches were replaced by large contacts which were arranged to short-circuit a portion of the transmitting inductance. The instrument was controlled by a Wheatstone Transmitter or hand key. Many of the large Radio Stationsl such as Leafield (Oxford), Cairo and Eiffe. Tower, were equipped with these (Figure 7),

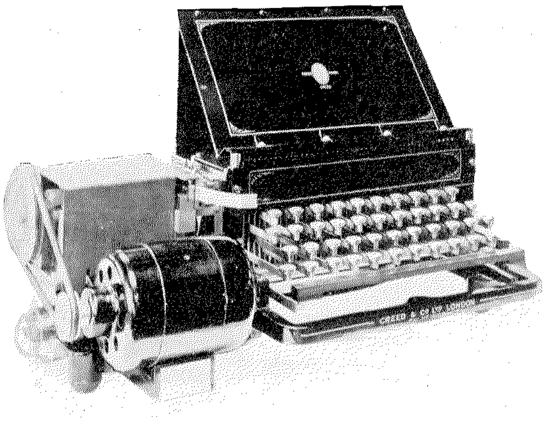


Figure 11—Morse Keyboard Perforator.

The Modern Reperforator

Effort was now directed toward the production of a Reperforator and Printer which would not be pneumatically operated. The necessity for an air compressing plant had always been recognised as a disadvantage; and the improvement effected by the removal of this necessity, in the case of the Printer, served to emphasise the advantages to be gained by its entire elimination.

As the result of two years' investigation and experiment towards this end, the present Reperforator and Printer were evolved, and the first models were put into service in 1921 by the Pacific Cable Board and Commercial Cable Company. Since that date, minor improvements have been introduced, but the general design remains substantially the same.

In the case of the Reperforator (Figure 8) the operation of the punching mechanism is carried out by a cam, frictionally driven, and under the control of a power relay. This control is effected through a simple escapement, which permits the cam to make half a revolution for every movement of the relay tongue. During the half revolution, the corresponding punch is forced through the paper. The method of correction adopted is similar to that used in the older type of machine, except that it is cam-operated. The power for driving the clutch and feeding the tape is derived from a shunt-wound motor, the speed of which is adjusted by means of a variable resistance in series with the field. Apart from the motor and the power relay, the action of the machine is entirely mechanical.

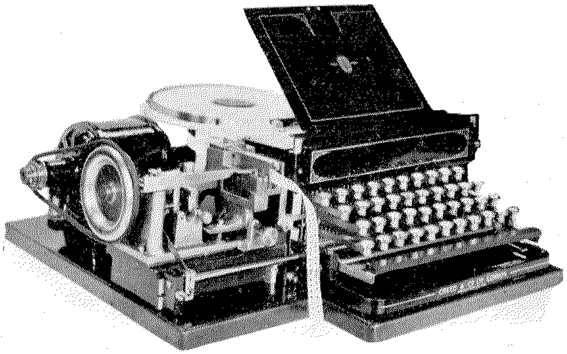


Figure 12—Morse Keyboard Perforator with Horizontal Tape Wheel.

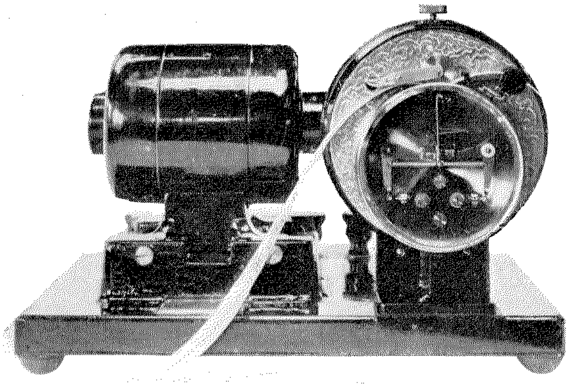


Figure 13—Morse Tape Transmitter.

The Modern Morse Printer

The Printer (Figure 9) also is a motor-driven cam-operated machine, and differs from the pneumatic printer principally in the method of setting up the selection, and the design of the typehead.

The Selectors themselves are very similar to those of the older machine, but in this case a combination disc is provided for each one of the twenty, instead of one for every pair. In this way the unwanted letters which may follow and occupy selectable positions, can be eliminated, by suitably cutting the combination on the discs.

The combinations are notched round the periphery of the discs. Arranged around them concentrically are a number of latches which can be raised and lowered on to the edges of the discs. According to the combination set up, a clear track is left across the twenty discs into which one latch is permitted to drop. It is so arranged that the end of this latch comes into the path of, and arrests, a rotating, frictionally driven stop, attached to which is the typehead. In this manner the type corresponding to the particular selection set up is brought to rest in front of a hammer, which at the correct moment, presses it forward on to the paper.

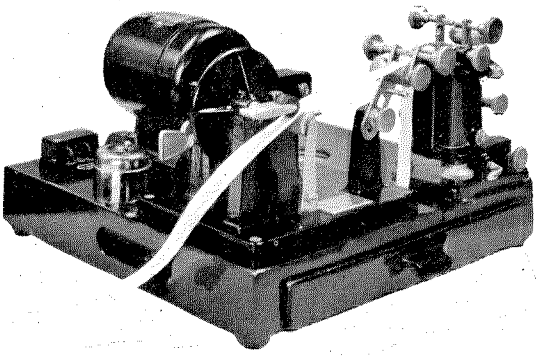
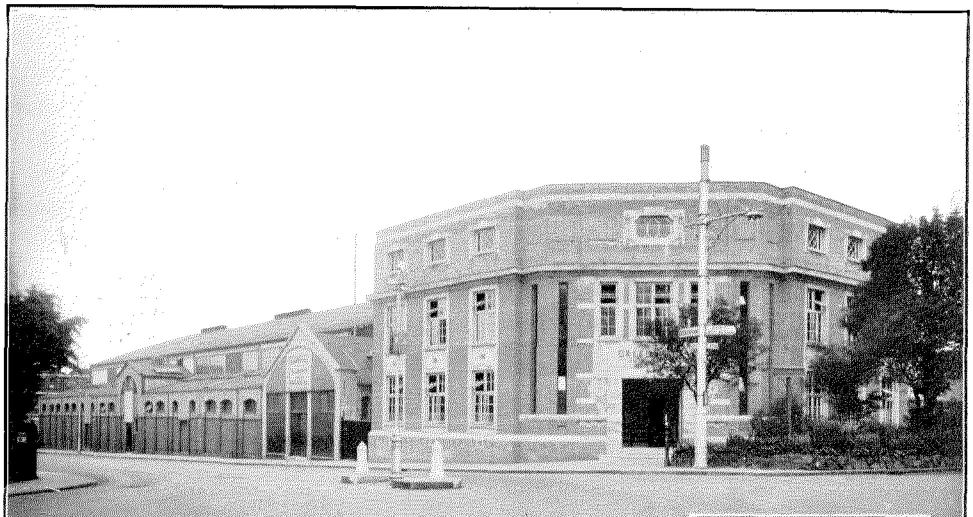
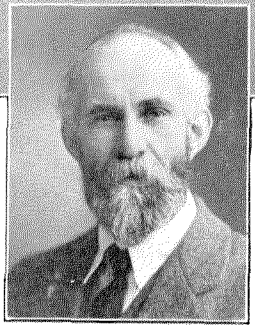


Figure 14—The Creed Undulator.

It was necessary to evolve a typehead of very light yet strong construction, which could be rotated at a high speed, yet stopped and restarted instantly. The weight of this typehead is 23 grammes (Figure 10). Each type is a separate bar, made of steel, hardened, and tempered. These are mounted on an annular pivot, and can be operated independently of each other.



Creed Works and Offices.



Portrait of the Author.

The method of achieving the differential feed of the perforated tape is identical with that used on the pneumatic printer.

The Modern Keyboard Perforator

The High Speed Morse Printing Telegraph System was completed by the provision of a simplified form of Morse Transmitter, Undulator, and improved model Keyboard Perforator, in 1922. The improved model Keyboard Perforator (Figures 11 and 12), avoids the use of compressed air, being cam-operated and motor-driven. The combination bars are arranged so that they can be positively held by the selector bars carrying the operating keys. The punches are supported in a frame, with their heads opposite to the ends of the combination bars. This frame also carries the paper tape, and at the correct time is moved by the cam, forcing the paper against the punches, and the punches against the ends of the combination bars. Those combination bars which are held by the depressed selector bar cause the corresponding punches to be forced through the paper tape. A differential feed mechanism is provided similar to that on the Printer.

The Automatic Tape Transmitter

The development of the secondary cell, and its introduction into telegraph service led to the use of universal batteries with their mid-points earthed. This rendered unnecessary one of the two pairs of contacts included in the design of the Wheatstone Transmitter, and it was obvious that a considerable simplification of the mechanism could be effected by the elimination of these unnecessary contacts. It was to this purpose that the Creed Morse Transmitter was developed.

Further simplification was made possible by the simultaneous development of a polarised relay, one of the special features of which was its very firm contact pressure. By using this relay in conjunction with the transmitter, it became possible to eliminate the jockey retention of the armature. The mechanism of the Transmitter was reduced to two bell-cranks carrying contacts oscillating under the action of an eccentric, and controlled through the usual "peckers" by the tape (Figure 13).

The Undulator

This apparatus (Figure 14) is used where it is required to record incoming telegraph signals in graph form. It embodies the principle of the Kelvin siphon-recorder, and consists essentially of a special type of quick acting galvanometer, and a light siphon tube with one end trailing on a paper tape, and the other end dipping in an inkwell. The paper tape is fed forward by a motor-driven mechanism. A variable gear permits the speed to be adjusted to suit the incoming signals.

The Undulator completes the group of apparatus units used in the High Speed Morse Printing Telegraph system now in widespread use throughout the world.

ERRATA: *Electrical Communication*, Vol. VII, No. 4, April, 1929.

Pages 283 and 289—Schematics of Figures 3 and 5 should be interchanged.

Page 285—In bracket at bottom of column 2, quantity $\frac{1}{2\pi C}$ at right should be separated from rest of the equation by a minus sign, viz., "$-\frac{1}{2\pi C}$."

Page 286—Bracket, column 1, second line, should read:

$$\left[\frac{K}{2\pi C\,[4-3K-\sqrt{(4-3K)^2-K^2}]}-\frac{1}{2\pi C}\right]$$

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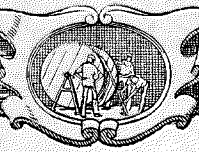

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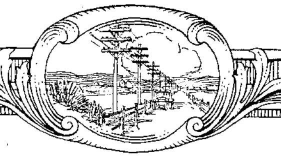

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CONTENTS

PAGE

PIONEERS OF ELECTRICAL COMMUNICATION, CLAUDE CHAPPE—IX 63
By Rollo Appleyard

DEVELOPMENT OF BROADCASTING IN JAPAN 81
By V. H. G. Parker

HIGH EFFICIENCY MULTIPLE MAGNETO BOARDS 89
By A. Capek

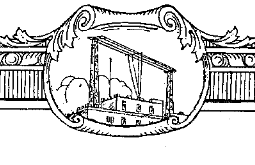
AUTOMATIC TELEPHONY IN THE ZÜRICH AREA 97
By E. Wollner

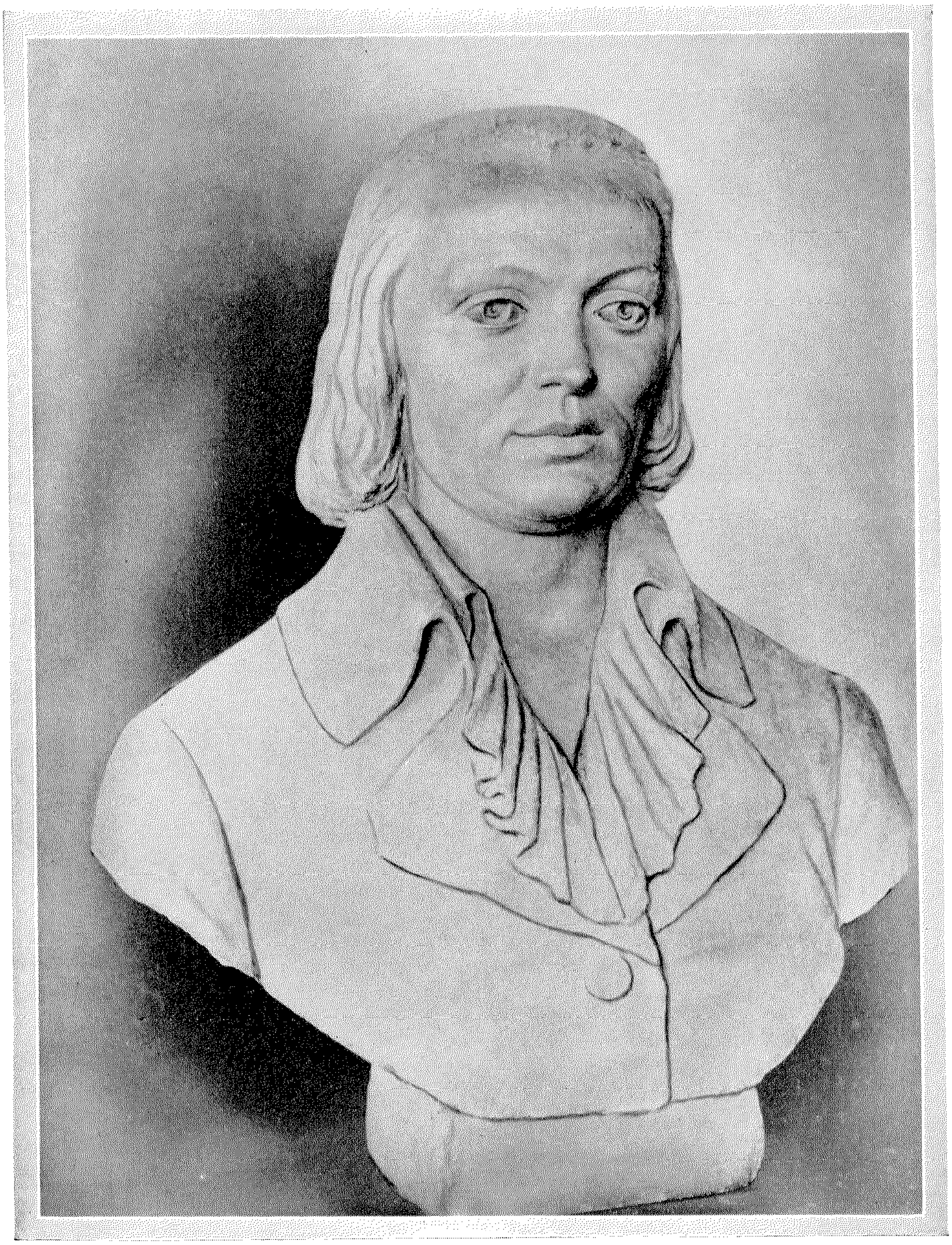
IN MEMORIAM—EDWARD BEECH CRAFT 108

THE ALUMINIUM ELECTROLYTIC CONDENSER 109
By R. E. W. Maddison, B. Sc., Ph. D. (Lond.)

TYPE D-1 SINGLE CHANNEL SHORT HAUL CARRIER TELEPHONE SYSTEM 122
By J. W. Sanborn

TELEPHONE AND TELEGRAPH STATISTICS OF THE WORLD... 128





Bust of Claude Chappe.

Pioneers of Electrical Communication
Claude Chappe—IX

by ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

THE principles governing successful communication over long stretches of land or sea have their origin in primitive optical, acoustic, and mechanical methods of signalling. Hints of them are found in legends of Chinese dynasties, in songs of ancient Greece, in tales of Roman campaigns, and in accounts of the enterprises of Elizabethan, Jacobian, and Georgian sailors. Through revolutions, wars, and reformations, the art of signalling by such means can be traced to the last years of the eighteenth and to the beginning of the nineteenth centuries, when it attained nearest to perfection at the hands of Claude Chappe—the first administrative telegraph engineer. Several biographies of this devotee of France have been published in his own country, but in personal detail they are all inadequate; the character and magnitude of his work, and the circumstances of the years of terror in which he lived, have almost obliterated the man himself. Upon that vast sea of trouble over which his endeavours to bring about unity by improved means of communication were as beacons to humanity, the track of his own career is little more than a ripple that loses itself in the gloom of his melancholy end. The best account of him is that written in 1893 by Ernest Jacquez, Librarian of Postes et des Télégraphes in Paris. From this it appears that Claude's father, Ignace Chappe d'Auteroche—parliamentary lawyer and Directeur des Domains of the King of France, at Rouen—married on February 13, 1762, Marie-Renée de Vernay de Vert, of Brulon. They had ten children, of whom only seven survived, i. e.,

1. Ignace-Urbain-Jean Chappe, born at Leval, November 26, 1762.
2. Claude Chappe, born at Brulon (Sarthe), December 25, 1763.
3. Marie-Marthe Chappe, born at Brulon (Sarthe), December 26, 1763.
4. Pierre-François Chappe, born at Brulon (Sarthe), August 11, 1765.
5. Sophie-François Chappe, born at Brulon (Sarthe), March 4, 1767.
6. René Chappe, born at Brulon (Sarthe), September 3, 1769.
7. Abraham Chappe, born at Brulon (Sarthe), May 6, 1773.

The father died in 1784. Claude was twin brother of Marie-Marthe. Of his boyhood little is known, except that he completed at a small school at La Flèche the studies begun by him at the Collège de Joyeuse at Rouen. He was educated for the Church, and he attained to being an Abbé Commendataire; this, however, did not necessitate his performing religious duties. He was early attracted to natural science, and he became acquainted with several physicists. One of his first experiments was with soap-bubbles that were filled with gas and then electrified. He found that if two such bubbles were charged oppositely, they attracted one another, and that under suitable conditions they detonated at contact. His researches were peremptorily brought to an end on November 2, 1789, when the benefice was suppressed by the Legislative Assembly. Claude then returned perplexed and miserable to the fatherless home at Brulon, where he found his four brothers, also thrown out of employment. He rose to the occasion, however, and decided to attach himself to the new regime of republicanism in France. This he did with zeal and devotion.

During an interval of comparative leisure in the country, in 1790, he conceived the idea of devising a system of communication that would permit his Government to transmit orders to a distance in the least possible time. He was aware that the problem was not new, and that it awaited solution. He discussed it with his brothers, who became his collaborators. As the result of his investigations during the next few years, three different systems were designed and operated. Briefly, they were:

(1) The Synchronised System, 1791.
(2) The Shutter System, 1791.
(3) The Semaphore System, 1792.

The first and second were examined by him tentatively. The third became established and was that most closely identified with his name.

System (1) depended upon the use of two clocks working synchronously at the sending and receiving stations, respectively. Each clock was provided with a rotating seconds-pointer that passed over divisions upon the face, and each division corresponded to a number. To transmit a phrase, the operator at the sending station struck a gong at the instant the pointer was passing the number to be signalled. A code was arranged for the interpretation of the numbers into words. In these experiments, the distance between stations was about 400 metres. As the system was impracticable for a line of many stations, Chappe endeavoured to replace the sound signal by an electric signal through a wire. Results were unsatisfactory, however, his insuperable difficulty at that time being the imperfect insulation of the conductor.

He failed to establish an electrical method. Accordingly he decided in favour of an optical system—depending upon the appearance and disappearance of surfaces of different colours and forms to indicate the precise moment of transit of the pointers past the numbers.

The first equipment used by him for (2), the Shutter System, consisted of two rectangular frames installed one at each station. The frames were fitted, respectively, with five shutters, each of which could be made to appear or to disappear at will. Further experiments revealed that elongated bodies are more clearly displayed than are shutters. System (3) was therefore devised, the equipment for which is indicated in Figure 3.

Meanwhile, a code to be employed with such signalling devices was developed by Delaunay, a cousin of the Chappes. Delaunay, who had been on the French consular staff at Lisbon, adopted as a basis the code that had been in service for diplomatic correspondence. This remained in use until 1795.

The story of the trials of those three systems is woven into the history of the French Revolution. A satisfactory demonstration that the synchronised system (1) could operate, was made on March 2, 1791, and the results were attested by responsible authorities. This was the beginning of a long series of experiments. The apparatus was often in imperfect condition, but it survived for more than a year, during which the Chappe family furnished means to cover the costs. Encouraged thereby, Claude, towards the end of 1791, went to Paris, and after many disappointments obtained authority to set up his machine at the Etoile. He was assisted by two of his brothers, and their efforts met with success. Success was short-lived, however, for one morning in September, 1792, revolutionary fanatics destroyed their apparatus, believing it to be a device for communicating with King Louis XVI, who at that time was incarcerated in the Temple. This disaster was to some extent a blessing in disguise, for it led to a transformation of designs, i. e., to the abandonment of the synchronised system, and to the adoption of the shutter principle. Disaster now followed fast upon disaster—this mechanism also was smashed and burnt by the mob. Undaunted, the brothers pressed on; they started anew with a semaphore system that ultimately became standard in France. The account of this was presented by Claude to the Legislative Assembly on March 22, 1792. He appealed for protection of his apparatus, and for a fair and conclusive trial of it by competent investigators.

At that time the Assembly itself was even less secure than the apparatus they were asked to defend. They were replaced by a Convention. The Convention of October 15, 1792, transferred the request to the Comitè d'Instruction, which also was too much occupied to deal with it. Meanwhile, the need for an efficient telegraph system had become urgent. Chappe therefore continued his efforts to perfect his machine and his code. On April 1, 1793, attention was directed to his work by Gilbert Romme (1750–1795), who was impressed by the possibilities of the Chappe system. So effective was Romme's argument that the Convention decided to allocate 6,000 francs for investigating and establishing the system. Moreover, Citizen Lakanal was directed to investigate it. The result of his report was that the National Convention accorded to Chappe the title of Ingènieur-Tèlègraphe, and an ordinance was published making it the duty of the Garde Nationale to protect the apparatus. The employees were described as "stationnaires" —a name that continued until 1862.

Claude bore his title of telegraph engineer to the end of his days. This, and the satisfaction of having served his country, was his solitary recompense. He never forgot what he owed at this critical stage to the referees, especially to Lakanal. He thanked him for the help he had given, and he praised his courage in the encounter against ignorance and against the prejudices of such revolutionaries as Cambon and Monot. It is pleasant to be able to record the complete and lasting fellowship of the brothers Chappe in the midst of this strife. This fellowship, and this alone, enabled them to overcome the difficulties of constructing long lines of communication, to organise transport, to instruct and control the staff, and to face the situation resulting from war and financial chaos.

The circumstances of the time forced the Comité de Salut to realise the vital importance of establishing a good system of intercommunication. From August, 1793, they made decrees, signed by such names as Couthon, Barère, Hérault, St. Just, Thuriot, and Robespierre, for its immediate extension. Chappe was authorised to place his machines in any belfries, towers, or emplacements he might choose, and he could cut down any trees that might interfere with the line of vision. The owners of the land and of the trees were to be suitably indemnified, and general provision was to be made by the Government—at least in theory—for hastening the work. Supplies of workmen, cash, and the means of transport, however, were not forthcoming. Against all odds, the brothers laboured, and with such vigour that, by July, 1794, a line was established and was actually working. It included the construction of fifteen stations between Paris and Lille.

Chappe did far more than devise a piece of mechanism and a code. He combined known ideas into a working system, and he caught the true spirit of telegraphy. He bridged the gulf between (1) the transmission of a signal whereby a pre-concerted message already written or otherwise recorded, and held for reference at the distant station, may be indicated, and (2) the transmission, if desired, of a series of elementary letters or numbers, whereby any message may be sent without previous conventions other than those relating to such letters or numbers. Leaving out of account the legendary telegraphs and the tentative achievements that preceded the work of Chappe, the first telegram sent and received by an organised system was that transmitted by him from Lille to Montmartre on August 15, 1794, acquainting the Administration in Paris that the French had re-taken Quesnoy.

France at that time, invaded on all its frontiers and on all its coasts, was endeavouring to train a new army by a levée-en-masse. Barère complimented Claude Chappe in a pronouncement to the *citoyens*, ending with words too true:

> "La récompense de cette invention pour les auteurs est dans la mention que j'en fais à cette Tribune."

On August 30, 1794, Chappe transmitted news of the recovery of Condé. This message arrived during one of the sittings of the Convention, and caused indescribable enthusiasm.

Today the names Quesnoy and Condé—i. e., Condé-sur-Escault, 12 km. north-east of Valenciennes—have comparatively little significance. In 1793–1794 they meant nearly everything. The wars of the French Revolution were at their height. The position of France was desperate. Her frontiers were assailed by allied forces including those of England, Holland, Prussia, Austria, Spain, the Italian States, Hanover and Hesse. The road to Paris was open, and the French army was not yet able to break the lines of communication of the enemy. Marseilles and Lyons had revolted against the French Government. An English fleet, on August 28, 1793, under Vice Admiral Lord Hood, held Toulon. Between France and perdition there stood but two barriers: (1) the incoherence of the allies, each having different objects in view, (2) the singleness of purpose that Carnot had succeeded in establishing amongst all units of the French army. Ultimately there was added to these the annihilating force of numbers that the French levée-en-masse brought into the field; for France was the most populous country in Europe. In 1793, Quesnoy and Condé had been captured by the allies, Mainz had surrendered to them, and Valenciennes had capitulated. In June, 1794, Carnot—after diligent preparation—began his campaign of unremitting attack, especially against the Austrians. The allies failed to concentrate; at the battle of Fleurus, June 25, 1794, they fell into confusion and were scattered, towards Holland and towards the Rhine. Then was it that the French under Jourdan regained the precious area that included the fortresses of Landrecies, Quesnoy, Valenciennes, and Condé. For about two months there was some suspension of active hostilities, but towards the end of 1794 frost set in with exceptional rigour, the Low Country became a continuous sheet of ice, and the French under Pichegrue and Jourdan proceeded to invade Holland. The allies fell back, the French pursued, and—welcomed by the Republican party of Holland—entered Amsterdam on January 18, 1795. A Dutch Revolutionary Committee then came into being, and some citizens of Amsterdam placed the three-coloured cockade in their hats. De Winter—who in 1794–1795 was a General of Brigade in the French service—to crown the victory, moved his troops across the ice and took posession of the Dutch fleet that he was destined ultimately to command. The actual operation was led by Moreau, of the French cavalry, who with the support of a single battery of horse artillery made a dash to the north, as far as the frozen Helderstroom. Sword in hand those troops traversed the Island of Texel and, to the amazement of Europe, captured the vessels. Without the telegraph these results could not have been achieved. The French war plans were drawn up under Carnot, a member of the Committee of Public Safety, and one of the best engineers in France. Edward Baines, writing in 1817, says:

> "The balloon—hitherto considered as a philosophical toy incapable of affording any solid advantage to mankind—was converted into an elevated observatory, by means of which the position, evolutions, and numbers of the enemy could be readily ascertained; at the same time that the telegraph, with a few simple motions, served to communicate the result of a siege, or of a battle, with the accuracy, if not the minuteness, of a dispatch, and with a celerity that in some measure rivalled the progress of sound."

It is therefore not surprising that when news of victories reached Paris the Assembly accorded praise to Claude Chappe.

In September, 1794, the Comité de Salut formulated a project to establish a telegraph towards the north by a semaphore system on the Chappe model, associated with distinguishing signals by flags. The work was begun, but financial difficulties impeded all operations. Promises of Government assistance vanished into thin air, and before the next year was ended, employees on that line to the north were dying of hunger. Yet, at the end of that year, another line was projected. This was to connect Paris and Landau (49° N. 8° E.). The construction was to be carried out in four divisions, centered respectively upon Paris, Chalôns, Metz and Strasbourg, under the management of Claude Chappe. His duties were administrative as well as technical, and he had charge of the factory in Paris where the equipment was made and adjusted. It was at this time that he left his quarters at No. 23, Quai d'Orsay, at the corner of the Rue du Bac, and went to No. 9, Rue de l'Université—the headquarters for his new Administration.

The scheme was laid down by the authorities with extreme care, but without funds. As Engineer-in-Chief, he was to receive 600 livres a month, and his brothers 500 livres each a month. Wages were fixed for the work, down to those of the office boy, who was assigned 125 livres a month. Unfortunately, along the slippery path of good intentions, payments failed to keep pace with promises.

It was at that time estimated that when the telegraphs were complete it would be possible to transmit a message to the extremities of France within an hour. The prime need was to ensure service between Paris and Strasbourg. From 1794 to 1798 service was actually maintained. The line passed through fifty stations, by way of Chalôns, Verdun, Gondrecourt, Saint-Quentin, Metz, Marimont, and Dingsheim. Difficulties resulting from lack of remuneration of staff led to painful results. An attempt was made to pay in kind instead of in cash, but not even this materialised. In default of payment, construction work in 1796 became disorganised. Workmen lost all zeal, and even the redoubtable Claude became despondent. Still more distressing were the conditions that he had to meet in the enterprise to the north. In his extremity, well knowing the penetrative and stimulating forces of a telegram, he turned his invention upon the authorities by dispatching to them the remonstrance:

> "Des fonds, des fonds, encore une fois, des fonds,

autrement nous ne pouvons rien faire. Addressez-les à Port-Malo" . . .

"Point encore de fonds, nous perdons depuis près de huit jours un temps extrêmement précieux . . . cette situation me desespère . . . Je fais tout pour assurer le prompt succès de l'établissement que je dirige; *de l'argent, ou point de ligne de Brest.* Salut et Fraternité. Chappe, ingénieur."

Yet he was invincible; he finished the line in seven months. It passed from Paris to Broué, Chaumont, Bruyères-aux-Bois, Avranches, Saint-Malo, Lanrodec and Guipavas, to Brest. This telegraph system remained under the administration of the French Marine until 1801. In 1799 the Strasbourg line with fourteen stations was established in Alsace for purely military purposes. It was abandoned in 1815.

An impression of Claude Chappe, loyal amidst all the turmoil. has been recorded by Jacquez. It is from a secret report from a Justice of the Peace at Lille to the Executive of the Central Bureau at Paris:

> "Le plus petit, qui est l'aîné et que l'on connaît ici sous le nom de l'ingénieur, parce qu'il est l'inventeur de la machine, a paru toujours joindre à beaucoup de lumières un attachement sincère à la République."

In an attempt to ameliorate conditions arising from lack of financial resources, Claude proposed to the Ministry that they should make a charge for telegrams:

1. For industrial affairs, commerce and banking.
2. For exploiting a newspaper.
3. For operations of a national lottery.

Only one of these suggestions was quickly put into effect—the lottery proposal, and this—as he predicted it would—paid for the greater part of the telegraph service. Amongst his other ideas, Claude devised a system of secret communication between Calais and Dover—a project taken up by his youngest brother, Abraham. It formed part of Napoleon's scheme to invade England in 1803.

During the years 1794 to 1799 Claude appealed to all the sentiments of the Administration, he had recourse to the most ingenious means to prevent the telegraph from suffering in the general distress, he formulated measures for placing the whole upon a sound financial basis, but the combined circumstances of strife within France, and aggression from without, at last weighed him down. Nerve and mind, under the load, began to revolt. The load increased, for in 1804, Napoleon demanded the immediate establishment of telegraph service between Paris and Milan by way of Lyons. Between Paris and Lyons there were ultimately fifty-eight stations.

The continual stress imposed by the new project severely tried Chappe. Nor was it only troubles arising from the work that undid him. In 1797 the usual cruel annoyances to which inventors are subjected by those who claim to have anticipated a successful device, had a disastrous mental effect upon him. He took up the challenge of those who claimed priority. This action was followed by the customary exchange of letters of incrimination and revenge. Then came the end. He had gone to study upon the terrain emplacements for further stations on the line to Lyons. He became restless and irritable and manifested symptoms of hysteria. At the completion of the work he returned to Paris, declaring that an attempt had been made to poison him in a village near Lyons. Finally he fell into a state of melancholy that no distraction could cure. On January 23, 1805, in a garden, his friends found his body at the bottom of a well.

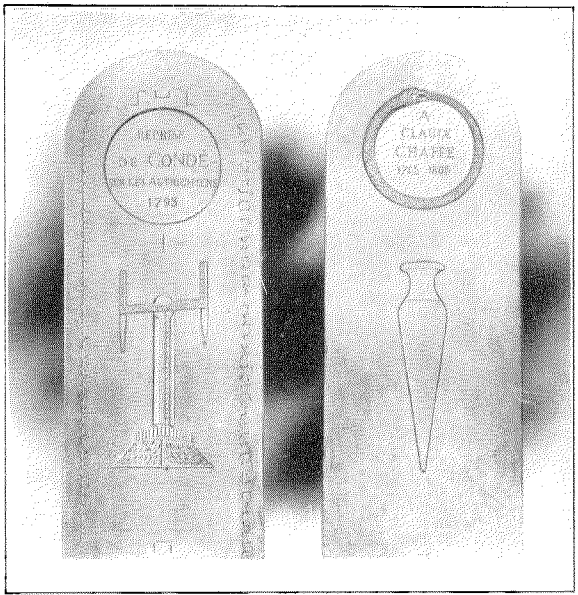

REPRISE DE CONDÉ SUR LES AUTRICHIENS 1793
A CLAUDE CHAPPE 1763 1805

Figure 1—Monumental Stones at the Entrance to the Administration of Telegraphs in Paris, No. 103, Rue Grenelle.

He was buried first in the cemetery at Vaugirard, but subsequently at Père Lachaise,

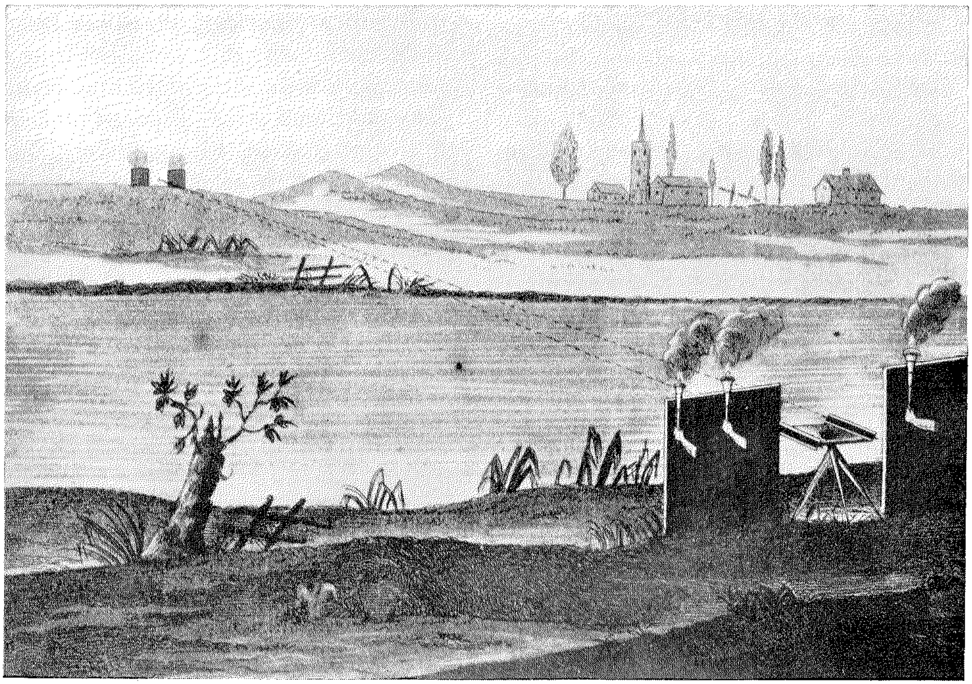


Figure 2—Ancient Greek Method of Signalling by Torches.

The alphabet is divided into five columns, of which four have five letters and one has four letters. Torches are hidden behind two walls—one to the left and the other to the right. To indicate the twenty-fourth letter, expose five torches to the right, which indicates the fifth column, and four torches on the left to indicate the fourth letter in that column. Tubes were fixed on each wall to direct the view. This method produced only feeble results.

at the side of his brother, Ignace, who died on January 25, 1829. The transfer took place on January 29, 1829. Their tomb bears the simple inscription "Chappe." According to M. Palhols, who investigated the matter, the tombstone from Vaugirard was presented in 1859 to the Administration of Posts and Telegraphs in Paris. It was then cut into two slabs (Figure 1) of half-thickness and placed at the entrance of No. 103, Rue Grenelle which since 1840 had been the headquarters of that Administration. The inscription contains two errors, for Claude Chappe was born in 1763, not in 1765; moreover, Condé was recovered in 1794, not in 1793, the date upon the stone.

It has been remarked by his biographers that the Chappe telegraph became famous first by the announcement of the recovery of Quesnoy in 1794, and that it ended its career in 1855 when it was called upon to transmit an account of an incident of like consequence—the taking of Sebastopol. In the Crimea, before transmitting this last message, it had served for eighteen months the military interests of the French army, and throughout moved with the troops.

Amongst the last of the Chappe telegraph services may be recorded:

1. Narbonne to Avignon by way of Montpellier (1831–1834).
2. Avranches to Cherbourg (1833).
3. Avranches to Nantes.
4. Bordeaux to Narbonne by way of Toulouse (1834).
5. Narbonne to Perpignan (1840).
6. Dijon to Bescançon (1840).
7. Bayonne to Behobie (1846).

In France, the Chappe telegraph was for many years in service, in harbours for signalling to vessels, on battlefields for signalling the positions and movements of the enemy, in sieges for signalling to the relieving contingents. By its means the Minister of War corresponded with Army divisions, and the Minister of the Interior with the Departments of France. At Paris, when this system had been perfected, they could receive communications from Lille in two minutes, from Calais in four minutes five seconds, from Strasbourg in five minutes fifty-two seconds, from Toulon in thirteen minutes fifty seconds, from Bayonne in fourteen minutes, and from Brest in six minutes fifty seconds.

From Paris to Behobie, at the far southwest of France in the Basses-Pyrénées, a signal could be sent under normal circumstances in about forty minutes. By 1852, at the moment that the electrical telegraph was substituted for the Chappe telegraph, the Chappe lines comprised nineteen branches, and a total length of more than 4,000 kilometres, including 556 stations. Similar lines, of a military character, working on a simplified system were established also in Algeria.

The angular settings of the wings were limited to seven positions, each 45° from the next—in practice making sixty-three variations, or 252 when combined with the four movements of the cross-arm. In its later form each setting could indicate a syllable or an entire word. The range was limited to that of their telescopes, i. e., to from six to eight miles on the level. The nearest telegraph to Paris was then at Montmartre. From Paris to Lille, from ten to twelve stations were necessary. At night, torches or lanterns were sometimes used upon the arms. In another method, for night service, translucent illuminated code signals or figures were employed.

In 1795 Chappe had pointed out that benefits might be conferred upon France by transmitting weather reports by his telegraph. A weather report service, however, was not completely organised until 1856.

The word "télégraphe" does not appear in his communication to the Assemblée Legislative of March 22, 1792. On that occasion he described his invention as a "tachygraphe"—rapid writer. In April, 1793, the word was changed to "télégraphe"—the far writer—as the result of a conversation between Ignace Chappe and Miot, Chef de Division à l'Intérieur.

Chappe was fully aware of the extent to which in ancient methods of communication the general principles of his devices had been adumbrated; he knew that the value of his work was in the adaptation of those principles to the needs of his time. He designed the mechanism to secure the greatest visibility, strength, lightness, durability and ease in operation.

The alternative systems (1) (2) and (3) happen to have been investigated by him in the sequence in which the basic principles came down through the ages. The first synchronised method in Europe probably dates from about 300 B. C., for the Greeks adapted their clepsy-

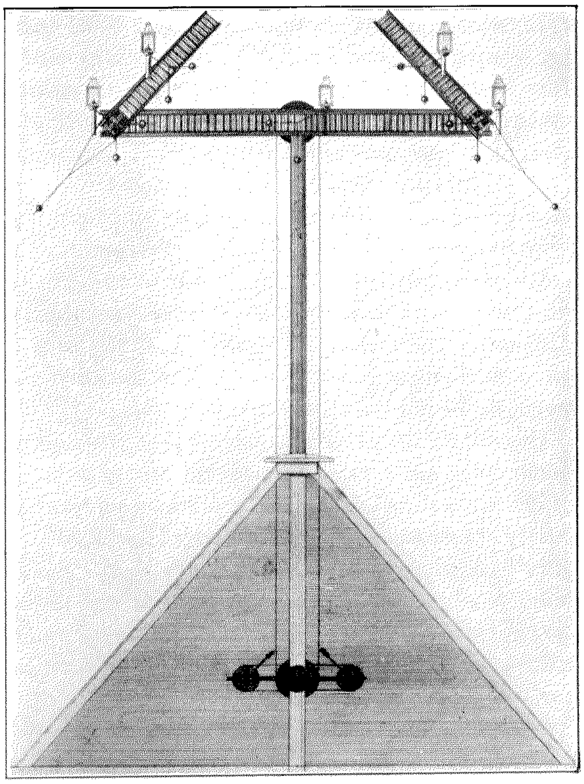


Figure 3—Le Télégraphe Francois, as Designed by Claude Chappe.

It consists, at its upper part, of three pieces, each of which is able to move independently. The large centre-piece or main arm, is a long parallelogram, at the extremities of which are fitted the other two pieces of wings, each able to take four angular positions, 45° apart. Together they can produce 196 shapes, each of which has a conventional value. The small "répétiteur" below the structure can be observed by the operator to check the movements.

drae to the purposes of signalling. The clepsydrae in effect were water-clocks depending upon a steady flow of water—literally the "*stealing*" of water—from or into a vessel containing a float. The float carried a vertical rod or flat strip. Upon such a strip phrases could be written in horizontal lines, or the letters of the Greek alphabet could be displayed in a vertical line. Arrangements were made for similar equipment to be supplied at successive stations along the line of communication. By raising a torch, the flow of water could be ordered to start at each station simultaneously. By raising the torch a second time, the flow could be stopped at all stations and the message could be read opposite a datum mark on the apparatus. In addition, the Greeks made use of a method sufficiently explained by Figure 2. The plan of communicating letter by letter was abandoned, and did not enter again into practice until the sixteenth century. The Romans and Gauls made use of signalling towers on a vast scale, and they certainly had a system of prearranged phrases with identification signals by beacon fires. Frequent use was also made of a line of signallers who shouted from mouth to mouth. Homer states that the voice of Stentor, the Greek herald in the Trojan war, was as loud as that of fifty men combined. Alexander the Great (323—356 B. C.) is said to have had means whereby a stentorian voice could be heard by all his army.

Questions of priority concerning pre-electric telegraphy are rendered complex partly because of the slow development of ancient devices, and partly because that development related not only to equipment, but to codes, cyphers, vocabularies, dictionaries, alphabets, and numerical arrangements, all directed towards facility of transmission. Questions of priority relating to early forms of telegraphy were disposed of once for all by Bouvet, a missionary to Asia, who pleasantly declared that the Chinese had used the methods for 4,000 years, and that they were all invented by Fohi, the founder of Chinese science.

Following upon the earliest workers, groups of inventors, including Kirchner (1550), Scheventer (1636), and the Bernouillis, endeavoured to transmit messages by means of musical instruments, each note representing a letter. One of the Bernouillis devised an instrument formed of five bells, by means of which he could express all the elements of the alphabet.

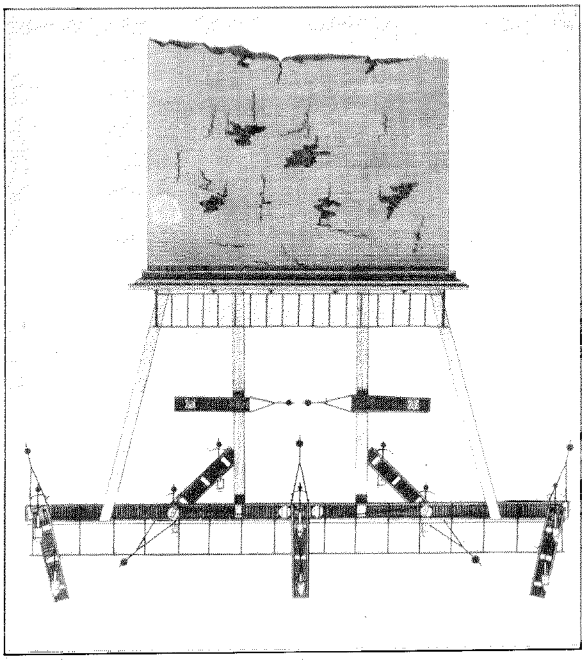


Figure 4—The Machine Invented by Monge about 1798. It was placed for a long time at the Tuileries, and a great number were constructed to operate on the line to Landau. Another machine was set up near Metz. According to Ignace Chappe, it never came into service.

The method of transmission of signals in England during the middle ages consisted in hoisting barrels or beacons upon masts, towers, or hills. At the beginning of the sixteenth century, occult science was in vogue, and those possessed of rudimentary scientific knowledge often preyed upon credulity by suggesting that they had powers of communicating by mirrors through the agency of the moon and stars and magnetic influence. François Kesler signalled letters of the alphabet by means of a lamp suspended from a hook in a subterranean tunnel. In front of the lamp was a screen that could be raised or lowered by a lever. He also signalled by the aid of smoke issuing from a barrel. In Kirchner's method, described in his "*Ars magna lucis umbrae,*" the message was written upon a mirror, the sun was the source of light, and the light was converged upon the distant station by a lens. It was a kind of magic lantern. Kirchner's object was "not merely to communicate the most secret thoughts of the heart to a distance, but also to transport to the eyes of a friend at an enormous distance your profile or silhouette." Thus Kirchner anticipated television. In 1663, the Marquis of Worcester suggested a day or night plan of signalling by exposing letter shapes.

There is a legend that in 1670 the King of England heard speech shouted through a trumpet from a distance of 1½ English miles, and that he sent the trumpet to Deal Castle. The Governor of Deal Castle reported that the trumpet enabled communication to be carried on across three English miles of sea. It was invented by that "ingenious mechanist" of Hammersmith, Sir Samuel Morland (1625–1695). The mouthpiece was shaped to prevent lateral loss of sound. Morland wrote a treatise on this "Tuba Stentorophonica" and in 1666 he also gave an account of "A new method of Criptography."

In 1762 Benjamin Franklin experimented with the transmission of sound under water. In 1783 came Ganty and Biot with their tubes. They transmitted speech through 395 metres of tube by speaking very loudly. At 951 metres, speech was scarcely audible.

In 1763 Monsieur de Morogues published his "*Traité des Evolutions et des Signaux*"—a theoretical treatise on signals in which he introduced the idea of having a special flag to indicate the signification of a set of flags, for example, numbers or letters.

A noteworthy advance in optical communication was made when so-called "Indian Fire" was imported to England for signalling purposes. It was used with specially good effect in 1787, when by means of it the Observatories of Paris and Greenwich were for the first time brought into agreement, across the English Channel. The "Indian Fire" was contained in small boxes that burnt for about 2¾ minutes; it is said to have been unaffected by wind or rain.

Under the title of "Synthematographie," F. A. B. Bergstraesser wrote, in 1785, a treatise in German on the earlier modes of signalling. He described methods of communication that had been used by day and by night for military and other purposes during the centuries. It was estimated that one of the schemes would require 6,000 or 7,000 "coups de canon" to dispatch twenty words fifty miles. He explained certain numerical and alphabetical codes, and the employment of various shapes and solid letters for mechanical signalling. Moreover, he gave an account of methods of transmission by rods and bevel gears, shutters, pivoted arms set at various angles, torches, lanterns, and in fact, by the whole of the devices available up to and during his time. A copy of his work, in five volumes, was presented by him to George III, and is now preserved in the British Museum Library.

Another remarkable treatise entitled "Histoire de la Télégraphie" was written by Claude's elder brother, Ignace Urbain Jean Chappe, who is described as "Ancien Administrateur de la Télégraphie." This was published in Paris in 1824. A second edition appeared in 1840. It embodies some of what is told by Bergstraesser, but in addition, it gives an account of the scientific principles to be observed, especially with regard to visual signalling; it reviews the contemporary state of knowledge of the subject throughout Europe at the beginning of the nineteenth century, and it includes some precious details concerning the work of Claude. This book contains a valuable introduction by Abraham Chappe, the youngest brother of Claude, in which is reviewed the history of the subject, with comments upon the part taken by the Chappe family in its development. Figures 2–6 are reproduced from this treatise.

Between 1808 and 1819 indirect light was thrown upon the subject by John Macdonald, F. R. S., a retired Lieutenant-Colonel of the Royal Artillery. In one of his contributions, he purported to describe "Experiments upon the Relative Times of Burning of Fuses"; but, fortunately for telegraph history, he digressed widely to attack "the present imperfect state of telegraphic communication." As early as 1797, Macdonald in England emphasised the importance of developing telegraphy as a science; he also prepared a telegraphic dictionary, and a three-figure system for conveying words, phrases, and sentences. In 1810 he laid his scheme before the naval authorities. Mr. Barrow—who was then "the man of science at the Admiralty"—declared the dictionary to be "precisely what is wanted." The result was, to some extent, satisfactory for the Royal Navy. Spelling was avoided. Everything was by numbers. Macdonald's next step was to point out that the telegraph, as it was applied on land in 1810, merely expressed one figure at a time. He urged the Admiralty to adopt a three-figure system for their line telegraphs.

He says that shutters were judged to be better adapted than semaphore arms to the English climate, "it being supposed that a certain number of shutters would be better seen than the same number of arms acting conjointly." This judgment, however, is in direct opposition to that of the Chappes. The shutter telegraph to which Macdonald refers gave sixty-three combinations. In the Royal Navy, at that time, three and sometimes four figures were telegraphed simultaneously, i. e., by one hoist of flags. He directed attention also to the relative merits, in regard to visibility, of a shutter and a "semaphoric wing." In particular, he pointed out the difference in this respect between an arm nine feet in length lifted high in the atmosphere, and a shutter grouped with five others at a low station. He asked for a trial of shutters against arms on a line of eleven or twelve miles. His book contains the following remarkable peroration:

> "It is unnecessary to dwell here on the incalculable benefit that would arise to commerce, to public revenue, to private convenience, and to public safety and security, by establishing a ramified telegraphic system, extending from the metropolis to the principal seaport towns, inclusive of a methodised intercourse with the principal cities situated to the right and left of such lines of communication. Such an undertaking would be a sublime attempt at an approximation of time and space; and would be truly worthy of the high character of our mighty nation. I, an obscure and humble individual, advanced in age, and passing on to that country from whose bourne no traveller returns, venture to prophesy that future ages will see this magnificent idea fully realised. Let it be recollected, that a less simple plan, the establishment of mail coaches, was at the time deemed impracticable and visionary. Man is a progressive animal."

Macdonald devoted great attention to the question of a numerical system. In the development of telegraphy, this was an important step, and he sums up the situation in a paragraph as follows:

> "The most essential improvement in naval signals has arisen from the invention and application of *numerical order*. This simple, but luminous improvement is generally ascribed to Monsieur de la Bourdonnais; but those who have looked closer into the subject, know that Bishop Wilkins in his "Secret and Swift Messenger" not only recommended the method of signalling by notation, but describes the mode of execution. Dr. Hook, who is the inventor of the Land Telegraph, a species of which he mentions, recommended a numerical plan to the Royal Society. Kirchner very nearly hit on the invention, and Gaspar Shottus in his *Technica Curiosa*, expressly mentions it. With all this, it must be confessed that Monsieur de la Bourdonnais brought the plan to considerable perfection."

The book referred to is "Mercury, or the Secret and Swift Messenger, shewing how a Man may with Privacy and Speed communicate his Thoughts to a Friend." It is by John Wilkins (1641) and is an ingenious work on cryptology and modes of rapid correspondence.

Between the years 1784 and 1788 a method of signalling by means of troops formed up into various shapes was suggested; and a Dutch officer, Boucheuraeder, trained soldiers to perform in this manner in Holland. Telegraphy became in fact a vogue, and there were not lacking then as now telegraphomaniacs who pestered Administrations with impracticable schemes.

Bergstraesser, Macdonald, and Ignace Chappe all paid tribute to a much earlier writer, Sir Robert Hook (1635–1703), the mathematician and advocate of aeronautics. The discourse given by this great Englishman at the Royal Society of London, on May 21, 1684, is concise and instructive:

Dr. Hook's Discourse to the Royal Society. May 21, 1684, on "Shewing a Way how to Communicate one's Mind at great Distances."

> "That which I now propound, is what I have some Years since discoursed of; but being then laid by, the great siege of Vienna, the last year, by the Turks, did again revive in my Memory; and that was a Method of discoursing at a Distance, not by sound, but by Sight. I say therefore 'tis possible to convey Intelligence from any one high and eminent Place, to any other that lies in sight of it, tho' 30 or 40 Miles distant in as short a Time almost, as a Man can write what he would have sent, and as suddenly to receive an answer, as he that receives it hath a Mind to return it, or can write it down on Paper. Nay, by the Help of three, four, or more, of such eminent Places, visible to each other, lying next it in a straight Line, 'tis possible to convey Intelligence, almost in a Moment, to twice, thrice, or more Times that Distance, with as great a Certainty, as by Writing.
>
> "For the Performance of this, we must be beholden to a late Invention, which we do not find any of the Antients knew; that is, the Eye must be assisted with Telescopes, of Lengths appropriated to the respective Distances,

that whatever Characters are exposed at one Station, may be made plain and distinguishable at the other that respect it.

"*First*, For the Stations; if they be far distant, it will be necessary that they should be high, and lie exposed to the Sky, that there be no higher Hill, or Part of the Earth beyond them, that may hinder the Distinctness of the Characters which are to appear dark, the Sky beyond them appearing white: By which Means also, the thick and vaporous Air, near the Ground will be passed over and avoided; for it many Times happens, that the tops of Hills are very clear and conspicuous to each other, when as the whole interjacent Vale, or Country, lies drowned in a Fog. Next, because a much greater Distance and Space of Ground becomes visible, insomuch that I have been informed by such, who have been at the Top of some very high Mountains, as particularly at the Top of the Pike of Teneriff, that the Island of the Grand Canaries, which lies above 60 Miles distant, appears so clear, as if it were hard by; and I myself have often taken Notice of the great Difference there is between the appearing Distance of Objects seen from the Tops and Bottoms of pretty high Hills, the same objects from the Top appearing nearer and clearer by half, and more than they do when viewed from lower Stations of the Hills; and this not only when the Space between them was land, but where it was nothing but Sea. I have taken Notice also of the same Difference from the Prospect of Places from the top of the Column at Fish-street-Hill, where the Eye is, in good Part, raised above the smoaky Air below.

"*Next*, the height of the Stations is advantageous, upon the account of the Refraction or Inflections of the Air; which Inflections of the Air are many and very great, sometimes in an Air which seems, to the naked Eye, the most clear and serene. Insomuch that That alone does wholly confound the Distinctness of Objects appearing at a Distance; now the greater Part of these arise from Commotions of the more dense Air that is near the surface of the Earth, by the Rarefaction of some Parts of it, caused by Heat; which rarified Parts ascending, do make the Objects seen through it, to seem to dance and undulate, which is in great part avoided, if the Prospect be from an higher Place. Besides, the Nature of the Air itself, at great Heights, approaches nearer to the Nature of the Aether, which more powerfully propagates the Impulses of Light."

He then explains that there must be no hill interposed between stations, because the air above that hill will be very apt to disturb the clear appearance of the object. There is to be one telescope at each terminal station, and two at each intermediate station, and times are to be agreed upon for operation.

"Next, there must be a convenient Apparatus of Characters, whereby to communicate any Thing with great Ease, Distinctness and Secrecy. There must be therefore, at Least, as many distinct Characters, as there are necessary Letters in the Alphabet that is made use of . . . and those must be either Day Characters or Night Characters."

His plan was to use shaped letters by day and torches by night, to represent either letters or whole sentences. He adds:

"I could instance a hundred Ways of facilitating the Method of performing this Design with the more Dexterity and Quickness and with little Charge; but that, I think, will be needless at present . . . The same Character may be seen in Paris, within a Minute after it hath been exposed in London."

He realised that there might be many applications of such a method, particularly for cities or towns besieged, and for "Ships upon the Sea."

Sir Robert Hook utilised two or more shapes to form a multiplicity of signals, as probably the Greeks did in time immemorial. Ignace Chappe points out that in like manner Sébastian Truchet had combined two tiles—each coloured in two tints arranged diagonally—to give sixty-four changes. Here was the germ of the *dot* and *dash*, and of kindred two-tone and double-key systems of telegraphy. Ignace Chappe gives credit to Buria, a member of the Academy of Science of Berlin, for having suggested the reduction of the alphabet to a set of signs formed of two characters, and for pointing out that by such a binary system, for example, two prisoners might communicate by two different sounds—a knock and a scrape—which could be done by the heel of a boot, another precursor of a two-tone scheme.

From this sketch of the condition of knowledge concerning telegraphy in the early days of the Chappes, it is seen that the task before them was not to discover but to select and to coördinate. Of ideas there was untold wealth; of those powers of discrimination that spring from scientific research, there was lamentable poverty. The importance of scientific investigation is well illustrated by the advance made by Claude consequent upon his mastery of the principles of visibility. Ignace has left a record of the results of these investigations. He explains that although it is easy to signal by an arm or a rod for a short distance slowly, difficulties increase rapidly with the distance and with multiplicity of stations. The moving part, whatever its shape, must be light enough for transport up mountains, towers and other buildings; it must have surface enough to be seen, and yet strength enough to resist wind. It must therefore be exceptionally strong. Movements must be rapid and simultaneous, they must demand very little force, they must be capable of exact repetition without confusion, they must be free from ambiguity, they must remain unaltered during exposure. The brothers found it well to have available a large number of primitive signals for service matters, and a phrase code for the operator. Economy of time had always to be considered. Exceptional difficulties arose, as Hook had predicted they would, from atmospheric changes and from the effects of refraction of heated air. Special attention had therefore to be given to the form and colour of the exposed bodies. Experiments proved that upon a white ground a black disc is lost sight of at less distance than is a black line of the same width. Of two unequal black lines of the same breadth, the longer is visible from a point more remote than is the shorter. Black is preferable to white, because the visibility of the contours of an opaque body results largely from contrasts between the object and the background. There is always danger that an exposed body will be confused with what is around it, even if it is a white body upon a black background, because the contrast only relates to the points or lines of apparant contact between two surfaces. Contrasts are diminished by vapours, clouds, and refractions. Black backgrounds diminish contrasts. To avoid these difficulties they raised the bodies above all other terrestrial bodies—as modern "sky signs" are raised.

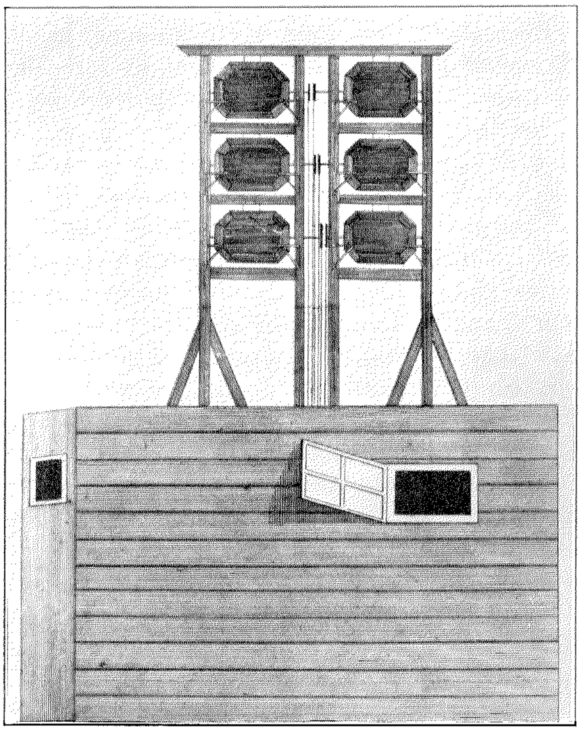


Figure 5—Apparatus Fixed on the Admiralty Building, Whitehall, London, in 1796.

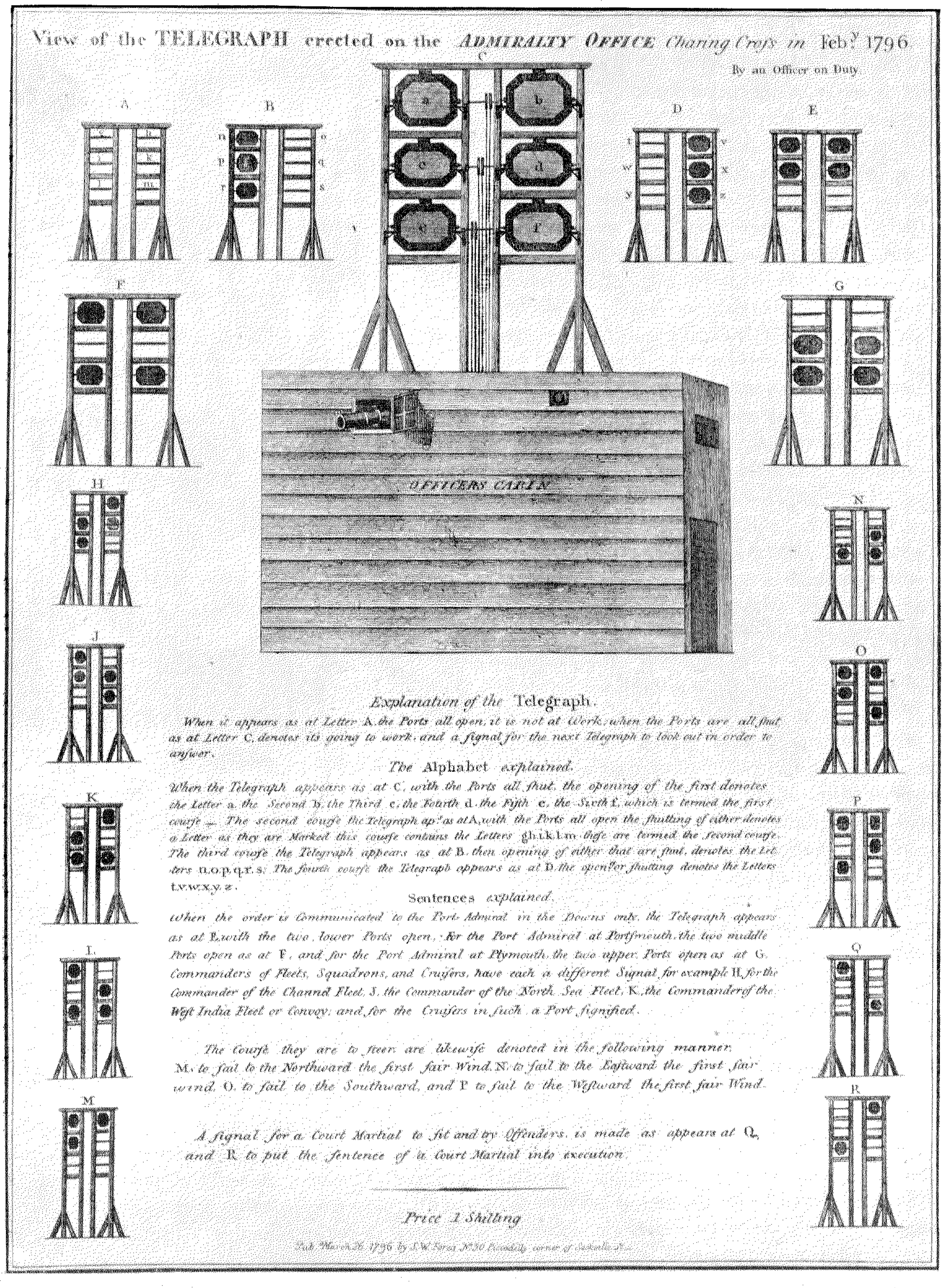
A frame with six shutters. It was sometimes necessary to make more than one signal to express a letter. Moreover, the proximity of the shutters to one another was apt to lead to confusion, especially in a smoky or foggy atmosphere. It is said to have served only twenty-five days in a year. A different machine, similar to Figure 8 was substituted, probably about the year 1810.

Experience showed that the shape of bodies seen at a great distance is lost when they reflect directly the light of the sun. It was for this reason that Chappe used planes inclined in various directions to form contrasts, or as Ignace says: "faire contraster, par ce moyen, le télégraphe avec le diaphanéité" of the atmosphere. The arms were therefore formed of inclined planes, resembling the sails of a windmill, (Figure 3).

Experiments were made to determine the best shape of opaque bodies for the purpose. A long parallelogram was found to be best. It had to be of comparatively slender construction, so as to present small resistance to wind. The battens were spaced to allow free passage of air, and they were sloped to prevent direct reflection of the sun's rays.

At first the diametral arm (Figure 3) was arranged to stop in one or other of six angular positions. Ignace says, however, that a body that is not perceived when it stands alone, may become so when it is near to another. Consequently, the number of angular positions assigned to the diametral arm was reduced to four, and a wing was added at each end of it. These wings were set in angular positions, thus increasing the number of signals that could be made with the machine. Each of the two wings could take seven positions with regard to the arm, the result being that 7 x 7 x 4 shapes were in general obtained.

Another principle at which they arrived was that acceleration is best achieved, not by unduly quickening the movements, but by care in ensuring that each signal conveys a clear idea.



View of the TELEGRAPH erected on the *ADMIRALTY OFFICE Charing Croſs in* Feb.^y 1796

By an Officer on Duty

Explanation of the Telegraph.

When it appears as at Letter A *the Ports all open, it is not at Work; when the Ports are all ſhut as at Letter* C *denotes its going to work, and a ſignal for the next Telegraph to look out in order to anſwer.*

The Alphabet *explained.*

When the Telegraph appears as at C, *with the Ports all ſhut, the opening of the firſt denotes the Letter* a, *the Second* b, *the Third* c, *the Fourth* d, *the Fifth* e, *the Sixth* f, *which is termed the firſt courſe — The ſecond courſe the Telegraph ap.^rs as at* A, *with the Ports all open the ſhutting of either denotes a Letter as they are Marked this courſe contains the Letters* g.h.i.k.l.m. *theſe are termed the ſecond courſe. The third courſe the Telegraph appears as at* B. *then opening of either that are ſhut, denotes the Letters* n.o.p.q.r.s. *The fourth courſe the Telegraph appears as at* D. *the open or ſhutting denotes the Letters* t.v.w.x.y.z.

Sentences *explained.*

When the order is Communicated to the Port Admiral in the Downs only, the Telegraph appears as at E *with the two lower Ports open, for the Port Admiral at Portſmouth the two middle Ports open as at* F, *and for the Port Admiral at Plymouth the two upper Ports open as at* G. *Commanders of Fleets, Squadrons, and Cruiſers, have each a different Signal for example* H *for the Commander of the Channel Fleet,* J, *the Commander of the North Sea Fleet,* K, *the Commander of the Weſt India Fleet or Convoy; and for the Cruiſers in ſuch a Port ſignified.*

The Courſe they are to ſteer are likewiſe denoted in the following manner: M. *to ſail to the Northward the firſt fair Wind.* N. *to ſail to the Eaſtward the firſt fair wind,* O. *to ſail to the Southward, and* P *to ſail to the Weſtward the firſt fair Wind.*

A ſignal for a Court Martial to ſit and try Offenders, is made as appears at Q, *and* R *to put the ſentence of a Court Martial into execution.*

Price 1 Shilling

Pub. March 26 1796 by S.W. Fores N.^o 50 Piccadilly corner of Sackville St.

Figure 6—Copy of a Print, now in the Admiralty Library, of the Telegraph of 1796, with Explanation of the Telegraph. Reproduced by kind permission of the Admiralty Librarian.

They therefore concentrated upon devising a good signal-manual and upon obtaining perfect control of the operators so as to avoid faults. Beyond a certain rate, quickening the movements was ineffective, because—as nearly simultaneous signalling was carried out at all the stations on a given line—there was overlap between stations in point of time. The essentials to be attended to, therefore, were perfection of code and faultless operation. The elimination of faults was dealt with in a drastic manner. Although the revolutionaries sang of liberty, equality, and brotherhood, the quality of mercy was not in their composition—negligence was punished by imprisonment. The members of the staff at each station were placed under a chief who could dismiss at will. To secure correct transmission, operators were selected of dull intellect, without ideas and without ambition. Wages for such "stationnaires," when wages were available, were twenty-five sous a day.

At intermediate stations the "stationnaires" had only to copy what was seen. Operators at terminal stations did all the code work. At each station there was a repeater to indicate what was being transmitted. In one system the signal was set when the arm was diagonal, and it was only read when it was either horizontal or vertical, i. e., in the confirmatory position. The movement from oblique to vertical or horizontal assisted the visibility of the signal.

Upon the Chappe principle, the French utilised for military purposes "télégraphes ambulants." In October, 1797, the French Government appointed Buonaparte to command an expeditionary force to attack England. In February of the next year he visited the French coast near Calais, and while he was pondering on a descent by a flotilla of small craft, it was realised that it would be very helpful to have at Gris Nez the means of signalling at night to Dover, while making the English coast. Accordingly, a powerful lamp was devised to work in conjunction with a large telegraph. The light from the lamp was to be projected by means of parabolic mirrors sixteen inches in diameter. It was upon the occasion of abandoning this scheme that Buonaparte declared that to effect a landing upon England without being master of the English Channel would be the most temerarious and difficult operation ever attempted, and it was for this reason that he diverted his attention to Egypt.

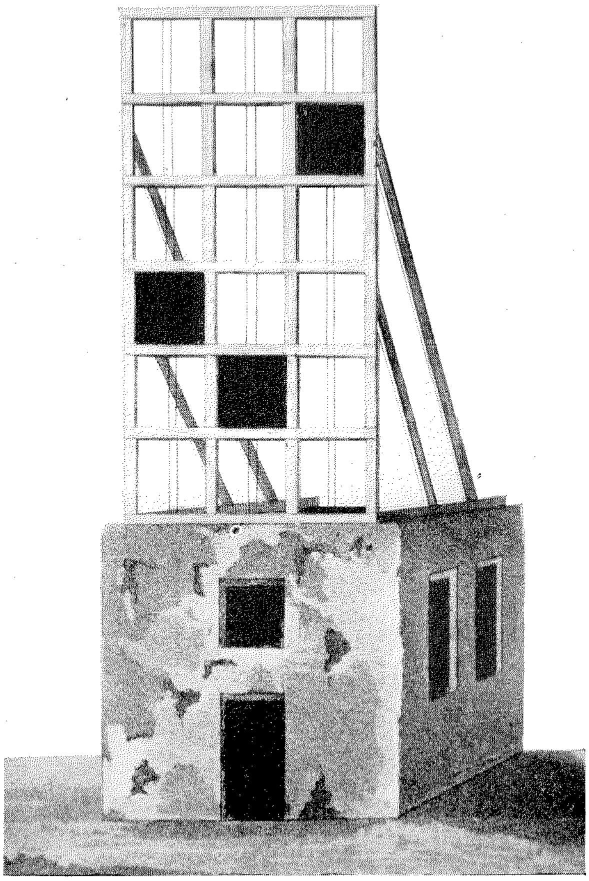


Figure 7—Apparatus Fixed at Plymouth.

It had only three shutters. These did not turn upon an axis, but they could be made to slide up or down to take a position at any of five openings in the frame.

The Chappe system was adopted in Egypt with considerable success because it was not subjected to alterations as in other countries. It is recorded that messages were sent between Alexandria and Cairo in forty minutes.

In 1794 Endelerantz developed the Swedish telegraph upon a plan somewhat resembling that of Chappe. A vertical post was provided with two arms forming a cross. The arms could be set at various angles to indicate letters. The apparatus did not produce enough signs for practical purposes. Endelerantz therefore substituted another design resembling a large rotating dovecote, with shutters. This was mounted upon a central vertical axis. At night he used occulting lanterns upon somewhat the same principle as the modern signalling lamp. The first trials of the Swedish telegraph took place between Drottningholm and Stockholm on October 30, 1794, and subsequent trials on August 30 and October 18, 1795.

When looking back upon the work of Chappe and his brothers, it is seen that they succeeded in solving three problems, and in uniting the results to establish a practical system of optical telegraphy. The first was the design of a machine, the second was to arrive at the principles in accordance with which the physical conditions could best be met, and the third was, out of the chaos of ancient suggestion to evolve a working code. It fell to the Chappes, in addition, to face administrative, political and military difficulties, and to succeed in circumstances of exceptional privation and danger. From beginning to end they were sustained by loyalty to France; their names deserve to be remembered as engineers who devoted themselves conscientiously to the welfare of their country, and as pioneers who made things easier for electrical communication that was to follow.

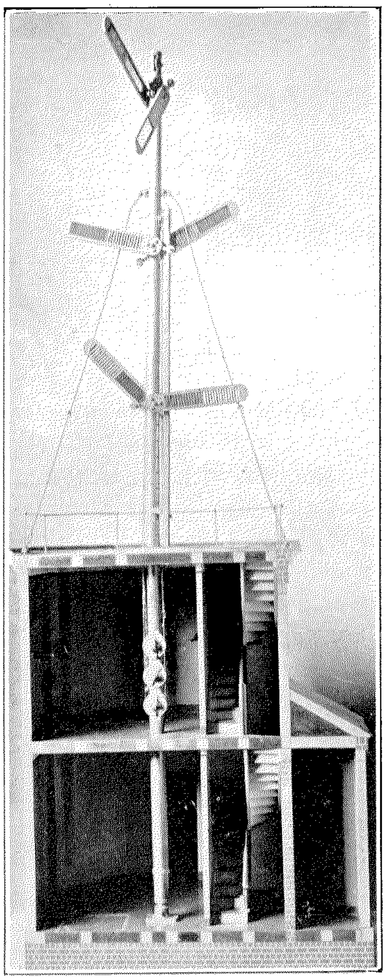


Figure 8—Model Preserved in the Verkehrsmuseum, Nürnberg, of the Optical Telegraph used at Möllenkopf near Ehrenbreitstein on the Rhine in 1833.

The development of the visual telegraph in France had its counterpart in England. A hint of the way in which information concerning the Chappe system was obtained by England is contained in Ignace Chappe's *Histoire.* Some other details of the development in England are to be found in an article by O. Tuck in "The Fighting Forces," Vol. I, 1924. Codes and signals are dealt with in the famous treatise "British Flags," by W. G. Perrin, Admiralty Librarian. From these various sources it appears that during the wars with France, at the end of the eighteenth century, a British officer at Menin observed what at first he thought to be a windmill with only two remaining sails. Occasionally the sails changed their angles with the horizon and seemed to make signals which were followed by the French troops. The matter was reported to John Gamble, chaplain to a member of the Royal Family. Gamble prepared an account entitled "Observations on Telegraphic Experiments," and in 1795 sent a copy of this to the Admiralty. He designed and constructed apparatus consisting of a vertical frame holding five shutters which could separately be opened or closed, allowing for thirty-one changes. Tuck mentions that at the time the Admiralty received Gamble's report there was no original telegraph system in England. Between the North Foreland and Land's End the Admiralty had forty-seven signalling stations. By means of hoists of various groups of black balls from yard arms at these stations, prearranged messages were communicated.

Preceding Gamble, another "inventor," Murray, fourth son of the Duke of Atholl, had produced a device comprising six shutters that gave sixty-three changes. Gamble and Murray were both in holy orders; and by another coincidence they both hit, in effect, upon a shutter telegraph, such as Chappe had long before aban-

Figure 9—Portrait of Claude Chappe.

doned in favour of a semaphore system. Gamble set up his trial shutter machine on August 6, 1795. He followed by designing a telegraph having radial arms, and offering this to the Admiralty. Their Lordships replied that They were:

> "... so well satisfied with the Telegraphs erected under the direction of Lord George Murray that they did not think it necessary to make any experiment with the radiated form."

To soften the blow, the letter was signed "Your affectionate friends." The truth is the contribution of Gamble added nothing to the information already in the possession of Their Lordships.

In the same year, 1795, a surveyor—George Roebuck—contracted to erect for the Admiralty fifteen stations between London and Deal at £230 a station. An eight-guinea clock and two twelve-guinea telescopes at each station completed the equipment. By January 27, 1796, a signal could be sent from London to Deal, and acknowledged, in twominutes. Roebuck was then appointed Superintendent of Telegraphs, with a salary of £300 a year. This work was followed by a line through Putney Heath, and Beacon Hill to Portsmouth, with ten stations, including Chelsea and the Admiralty. There was also a project in 1801 for a line to Yarmouth, but the peace of Amiens intervened and the scheme slumbered. So profound was the peace that signal stations along the eastern and southern coasts of England were abandoned to the owners of the land on which they stood.

War in 1803 again shook the world, and in 1805 Roebuck was active between London, Portsmouth, and Plymouth. The Plymouth line —200 miles—was completed on July 4, 1806, and Tuck says that a reply from Plymouth began to be spelt out only twenty minutes from the time that same telegraph had made "Message ended." The one o'clock signal could be made and acknowledged in three minutes.

In 1807 the Yarmouth scheme was resuscitated—the trail was through Chelsea, Hampstead, St. Albans, and the Gog Magog Hills near Cambridge, in all eighteen stations. By the middle of 1808, Roebuck had altogether sixty-five stations under his supervision, operated by the shutter system.

Between the years 1811 and 1816 the semaphore gradually replaced the shutter system in England. With the peace of May 1, 1814, when Napoleon was banished to Elba, there was again general relaxation and abandonment of signalling stations. But fortunately for English telegraphy he escaped and landed in France on May 1, 1815. Telegraphs were re-established with all haste and there was a general order to adopt the semaphore method. In November, 1815, a line was projected through West Square, Southwark, Nunhead, and Red Hill, to Chatham. Peace, however, followed Waterloo, the telegraphs were all paid off, and Roebuck's work was at an end. The Chatham line had nevertheless established the superiority of the semaphore method. In 1818 there was an effort to restore the telegraph service, especially on the line to Portsmouth.

In 1819 the English Ambassador in Paris requested the French Government to give England a model of the French telegraph. This was immediately done; but as the model was not accompanied by instructions, it was not used in England to best advantage. Although stray information concerning it had been obtained earlier, the principles necessary for its proper working had not yet been grasped in England. This Chappe machine was installed at Nunhead, where it remained until it was replaced by the Popham machine. By 1830 the telegraph system in England was again almost out of action. In 1838 Wheatstone was transmitting electrical signals from London to Birmingham, and on December 31, 1847, the last of the English Semaphore stations closed and the occupants of stations were discharged.

To link the history of the Chappe system with that appertaining to earlier methods of signalling, so far as England is concerned, requires retrospective vision. In the reign of Queen Elizabeth it became the custom for commanders of fleets to receive a set of signals and sealed orders for their guidance, just before going afloat. The method was developed by the Duke of York, afterwards James II, who as Admiral of England introduced a system of signals for Divisions of Fleets as well as for single ships, whereby they could be directed in a specific manner. James II was also the first to adopt scientific formations of line, and an order of battle. These instructions led to the British Naval Code. In France, Le Père Hoste, who wrote in 1697 a book on naval tactics, introduced in 1727 a system of signals by means of sails, flags and gun-fire. Thus the advance of practical telegraphy was along two converging paths, i. e., (1) Visual transmission devices, and (2) Codes. In the work of initiation, England and France were alike conspicuous, and history has fairly distributed the honours; for while Ignace Chappe himself frankly states that the nearest approach to the true principles of the art of telegraphy was made by Dr. Hook in 1684, Macdonald—who also lays stress upon the importance of the work of Hook—does whole justice to Claude Chappe, by giving credit to him for a great achievement in the development of "Semaphoric wings." Tuck tells us that the idea of running a commercial telegraph system in England was almost realised in 1842, when one day there appeared on the Shot Tower, near St. Olave's Church, on the south side of London Bridge, the inscription: "Watson's telegraph to the Downs." Watson had bought up the old telegraph and semaphore stations, and he proposed to run them as a commercial speculation. Unfortunately, however, the semaphore on the Shot Tower was destroyed by fire on August 19, 1843, and it was not re-erected.

The condition of mechanical and optical telegraphy in England at the time when the electric telegraph was beginning to be established, can be gathered from a Parliamentary Return, now out of print, relating to the London-Portsmouth line:

Admiralty Semaphore, 24 April, 1843.

A Return of the Number of Hours in the Day appointed by the Admiralty Printed Instructions, dated 4th December, 1827, for the Ordinary Working of the Semaphore from London to Portsmouth.

From the 1st October to 28th February, from 10 a. m. till 3 p. m. . . . . 5 hours.

From the 1st March to 30th September, from 10 a. m. till 5 p. m. . . . . 7 hours.

Note. Notwithstanding the above regulation, a look-out is kept at the several semaphores, and the closing sign is not made on any evening until their Lordships' commands are taken; those commands are never applied for whenever the sight is good until 4 o'clock p. m. in the winter, and 6 o'clock p. m. in the summer, and the line is kept open if required.

A Return of the Number of Days, during a period of Three Years, ending the 5th April, 1842, when the Semaphore was not available, by reason of the State of the Atmosphere.

Dates	Admiralty, Number of Days	Chelsea, Number of Days	Putney, Number of Days	Portsmouth, Number of Days
From 1839–40	133	64	42	21
From 1840–41	106	70	49	28
From 1841–42	84	77	51	16
Total Number of Days at each Station for Three Years.	323	211	142	65

Note. Whenever the working of the Semaphore at the Admiralty is prevented by reason of smoke, the State of the atmosphere to the eastward, or westward from the vapour arising from the water in St. James's Park or other causes, messages are on such occasions, when of importance, taken to or from Chelsea or Putney stations, and generally effectually communicated from thence to or from Portsmouth.

(Signed) CHARLES H. JAY,
Commander, Superintendent.

Semaphore (London to Portsmouth)
Return to an Order of the Honourable The House of Commons, dated 6th April, 1843:—for

A Return of all expenses appertaining to the Semaphore from *London* to *Portsmouth* for the Three Years ending the 5th day of April, 1842, including the Pay of the Officers and Men; also of the Number of Hours in the Day appointed by the Admiralty for the Ordinary Working of the same:—And of the Number of the Days during such Period of Three Years when the Semaphore was not available, by reason of the State of the Atmosphere.

Admiralty H. F. AMEDROZ,
2 May, 1843 Chief Clerk.

Ordered, by The House of Commons, to be Printed, 5 May, 1843.

Admiralty, 28 April, 1843.

A Return of all Expenses appertaining to the Semaphore from *London* to *Portsmouth*, for the Three Years ending the 5th April, 1842, including the Pay of Officers and Men:

	£ s. d.	£ s. d.
1839.	3,269 3 3	
Abate, Half-pay the Officers would have been entitled to if unemployed.	1,500 12 0	1,768 11 3
1840.	3,293 19 6	
Abate, Half-pay as above . .	1,514 15 0	1,779 4 6
1841–42.	3,653 5 0	
Abate, Half-pay as above . .	1,558 11 6	2,094 13 6
		£5,642 9 3

Memorandum. The above Return has been made up to the 31st March, the termination of the Financial Year of this Department, to which date the Accounts are rendered.

(Signed) J. T. BRIGGS,
Accountant-General of the Navy.

Development of Broadcasting in Japan

By V. H. G. PARKER

Engineering Department, Standard Telephones and Cables, Limited

DURING the year 1928 immense strides were made in the development of broadcasting in Japan. These developments were a natural sequence of the original scheme[1] projected when the Japanese Broadcasting Association was formed in 1926. Six new broadcasting stations, distributed over the three main islands of Japan, have been opened with the idea of bringing as many listeners as possible within crystal range of some station. Four of these stations serve areas which heretofore have been without local broadcasting service, while two of the installations—at Tokyo and Osaka, respectively—replace existing stations of lower power.

The new stations are each rated at 10 kilowatts unmodulated antenna power and are housed in entirely new buildings so as to leave the original transmitters still available in case of emergency. The only area not affected by the year's changes is that surrounding Nagoya, where a previous 1 KW installation remains in operation. The map (Figure 1) shows how the stations have been distributed among the main cities of Japan so as to cover as large an area as possible. Medium wave lengths are used throughout, and the entire broadcast wave length lies between 400 and 350 metres.

All call signs in Japan are given out in English and consist of four letters commencing with J. O. and ending with K. The third letter is different for each station and thus serves as a means of identification. The following is a list of the seven stations giving regular programmes, together with their call signs and wave lengths:

Sapporo	Sendai	Tokyo	Nagoya
JOIK	JOHK	JOAK	JOCK
361.4	389.6	375	360

Osaka	Hiroshima	Kumamoto
JOBK	JOFK	JOGK
385	353	380

The equipment of all the stations has been imported from England. Sapporo, Sendai, and Hiroshima have each been supplied with "Standard" Radio Equipment, designed and manufactured by Standard Telephones and Cables, Ltd., and installed by the Nippon Electric Company, Ltd.

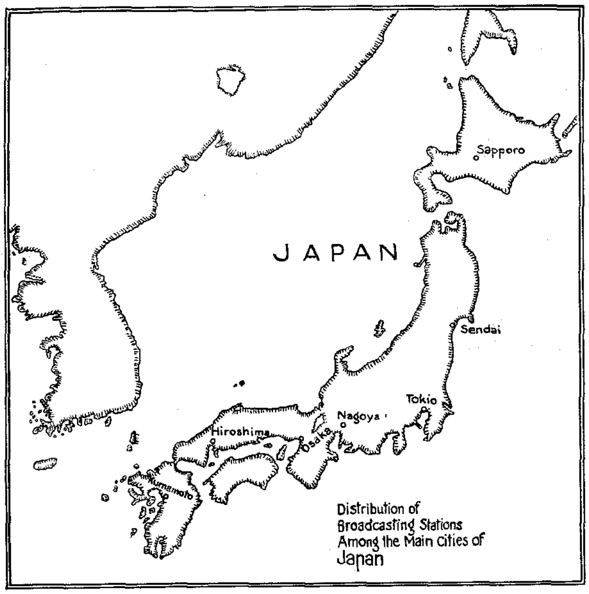

Sapporo
JAPAN
Sendai
Tokio
Nagoya
Hiroshima
Osaka
Kumamoto
Distribution of Broadcasting Stations Among the Main Cities of Japan

Figure 1—Map of Japan.

Sapporo (Figure 2) is the main city of Hokkaido, the second largest island of Japan; it has a population of 145,000, and owes its growth mainly to the public institutions established there by the Japanese Government. It possesses an Imperial University which in the past has been mainly devoted to the study of agriculture. The town itself, unlike other Japanese cities, is laid out in blocks and streets like an American city, all streets crossing at right-angles. The winter in Sapporo and on the island generally is very severe. For five months in the year, most of the country is frost-bound and covered with snow, often to a great depth, and all the roads outside the cities then become impassable except by sledge.

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[1] R. E. A. Putnam, "Broadcasting in Japan," *Electrical Communication*, Vol. V, No. 3, January, 1927.

The Sapporo Broadcasting Station was officially opened on June 5, 1928. By the end of July, 11,000 listeners had been registered.

Figure 2—(Sapporo) Nakajima Park in Winter. The Studio is Among the Buildings at the Back.

Sendai, with a population of 143,000, is the chief town in the north of the main island. It is an important educational centre and includes the famous laboratory known as the "Institute of Metallurgical Research." This laboratory is directed by Professor Honda. Important work in connection with cobalt magnet steel, better known as "K. S. Steel," has been done there. The University also gives special attention to radio research and has a very well-equipped laboratory for this purpose. Sendai is the headquarters of the Second Army Division, and many military students are quartered in the city. In the early part of the year, the Japanese Institution of Electrical Engineers held a large convention in the town. During this period, a very large number of visitors was shown over the station, which had just begun testing. The station was officially opened on June 23, 1928, and by the end of July 9,000 listeners were registered. The situation of this station is probably the most favourable of the three, and reports of very good reception have been received from all over the country—several from such distant points as New Zealand.

Matsushima, one of the three chief beauty spots of Japan (Figure 3), is situated only a few miles from the transmitting station.

Hiroshima, a port on the Inland Sea, is one of the chief military stations of the Empire. It has a population of 150,000, and is one of the most important commercial centres in the southern part of the main island. The country around Hiroshima is very mountainous and is covered with vegetation. The neighbourhood contains some of the most beautiful scenery in Japan, the best known being Miyajima, with its singular *torii* and famous shrine which, at high tide, appears to float on the water. The station was opened on July 5, 1928, for regular broadcasting, and reports of good reception have been received, notwithstanding the unfavourable nature of the country.

Building Arrangements

In designing the layout of the new stations, a general uniform plan was so far as possible adopted. Since Standard transmitters require less space than the other imported equipments, two different floor plans, suitable for each type of equipment, were selected. The three stations, Sapporo, Sendai, and Hiroshima, were each built to a uniform plan.

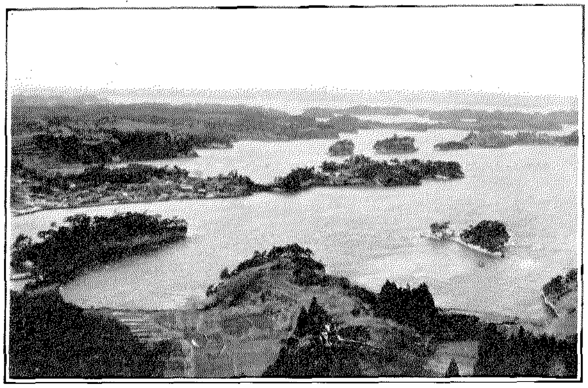

Figure 3—Matsushima (Pine Islands).

The transmitters have been located outside of and near to a main city, the distance being of the order of five to six kilometres, while the main studios and general offices have been built on some convenient site in the town itself. The buildings housing the transmitters are constructed of reinforced concrete, and are made as strong as possible in order to withstand earthquake shocks. Possible expansion has been provided for and the transmitter rooms have been made large enough to accommodate second equipments. In each case, large power rooms containing the machines, main switchboards and water cooling pumps and radiators have been provided, together with the necessary overhead gears for moving the power units. Figure 4 shows a corner of one of the power rooms containing the main switchboard and induction regulators. A control room containing the line amplifier equipment and a small local studio for announcements and general emergency work are a necessary feature of each station. A reception room, offices for the accommodation of the engineering staff, and a small workshop and laboratory have been included.

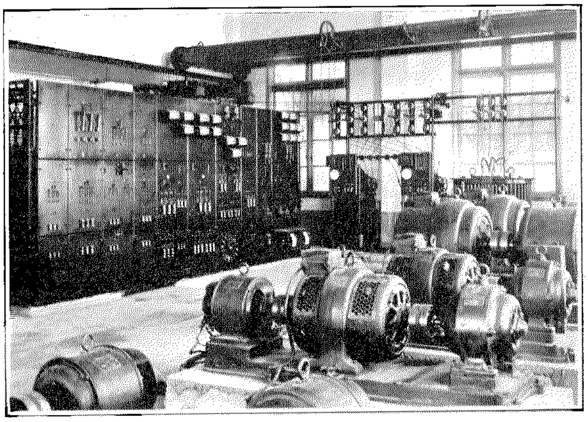

Figure 4—Corner of Power Room (Sendai).

Reliability and safeguard against interruption of the service have been the keynote of the general scheme, and all the main units of the equipment and power machinery have been duplicated where possible. In pursuit of the general plan, the power supplies are obtained from two independent power companies, and the operation of a switch brings either supply into use in a few minutes.

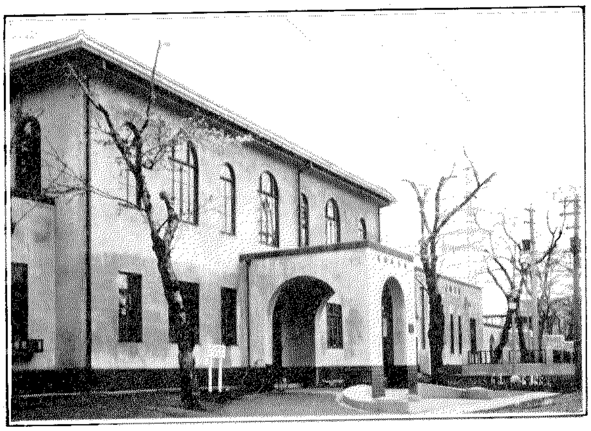

Figure 5—Studio Building (Sendai).

Three-phase power is supplied to the buildings at 3,000 volts per phase, which is then transformed down to 220 volts per phase for operating the radio transmitters. Induction regulators are employed to keep the voltage constant during variation of load. The water for the buildings, including that necessary for cooling the valves, is drawn from wells sunk in the grounds of the stations. This arrangement is considered adequate for the purpose, but the commercial town supply is also available in case of emergency.

The studios located in the towns are housed in concrete fire-proof buildings of two stories. They also contain the general offices and reception rooms. Figure 5 shows the typical construction of the outside of the buildings, Figure 6 is a typical reception room, and Figure 7 shows part of the main studio at Sendai.

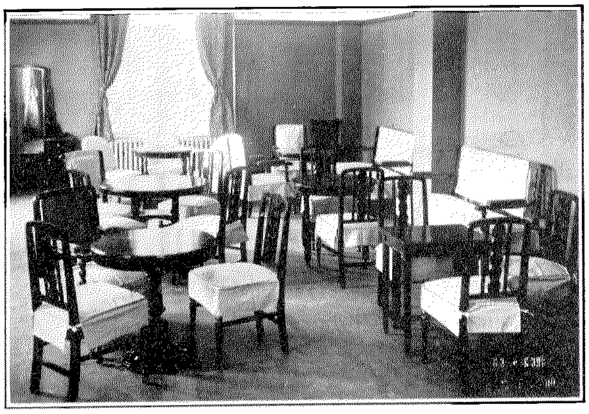

Figure 6—Typical Reception Room.

Two studios are provided, one large enough to accommodate a small orchestra and to be generally used for musical entertainment, and a smaller one for news bulletins, announcements, and lectures. The control room is between the two studios so that the operator has both under his immediate control. Here, again, battery supplies and the main part of the equipment are in duplicate.

Equipment

The radio transmitters installed are rated at 10 kilowatts in the antennae, and they are of a type representative of the latest production of Standard Telephones & Cables, Ltd. They employ low power modulation in conjunction with master oscillation control of the carrier frequency —with the well-known advantages. The equipment is of the dead front panel type. Figure 8 shows the front of the transmitter as installed at Hiroshima. The rear view, indicating the layout of the spare apparatus, is represented in Figure 9.

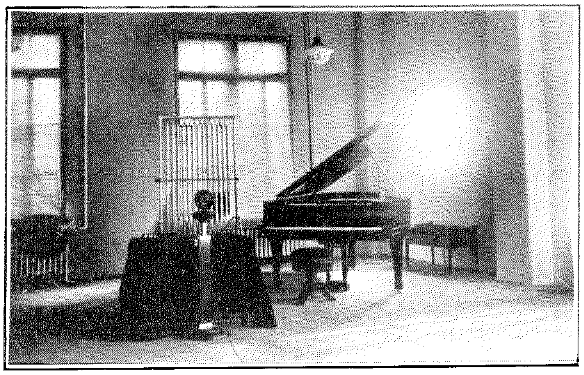

Figure 7—Part of Main Studio (Sendai).

On account of the distance between the radio transmitter and associated studios, two sets of speech input equipment are provided with each station installation. That installed at the studio is the Standard ES-771 equipment, which includes the usual studio pick-up amplifier, volume indicating and control devices, and monitoring facilities for audibly checking the quality of the studio programme, either at the output of the studio amplifier or at the output of a radio receiving set tuned to the associated radio transmitter. Such a set is shown in Figure 10, embodied in the sections at the left. The section at the right includes the spare amplifier, volume control, and equalizer to meet local requirements, and is all wired up and available for emergency operation by merely throwing the necessary keys.

The second set of speech input equipment

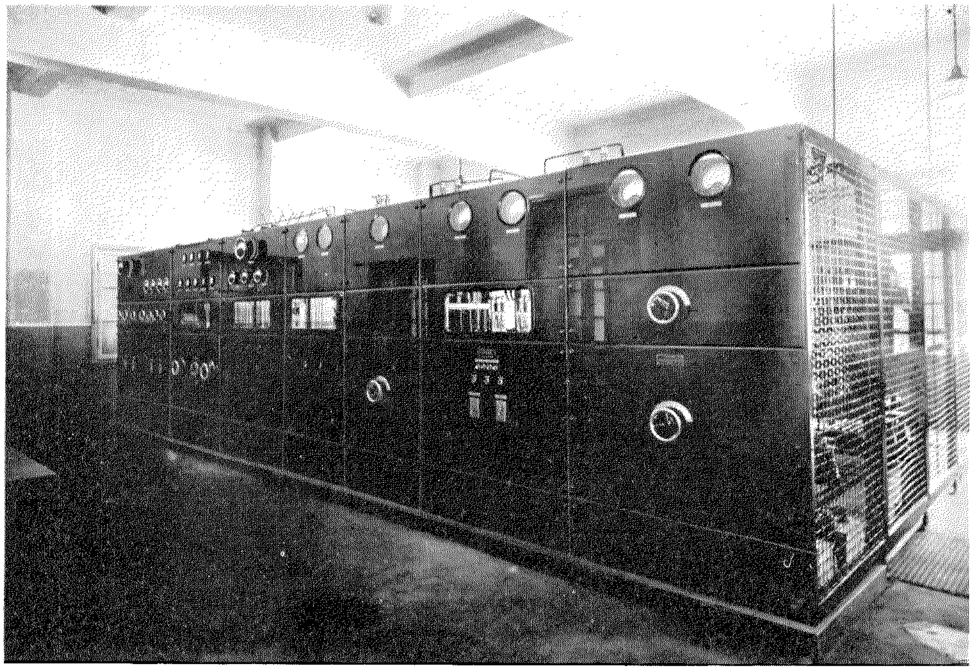

Figure 8—Transmitter, Front View (Hiroshima).

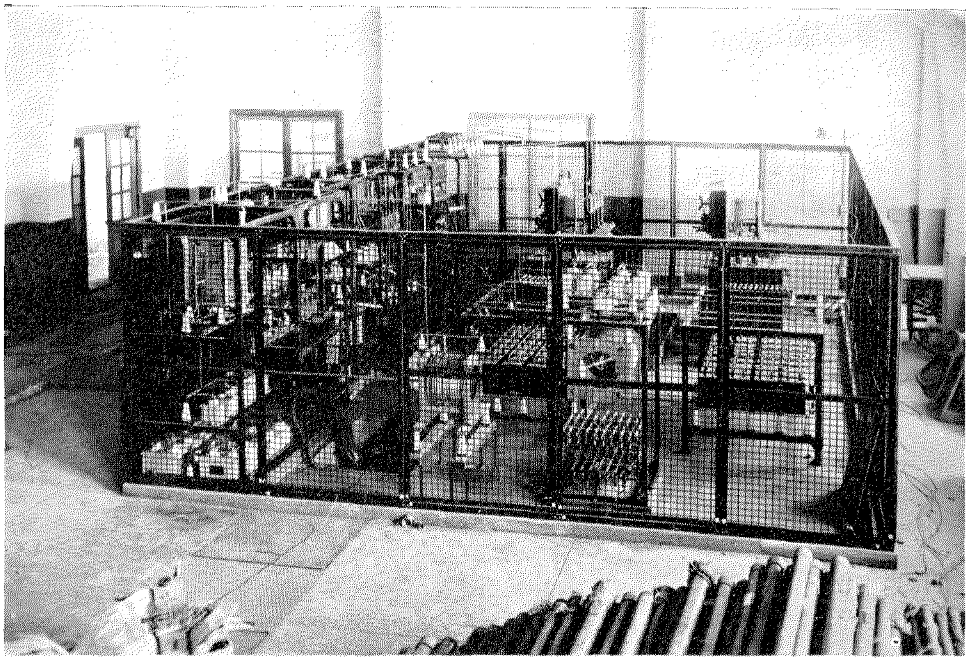

Figure 9—Transmitter, Rear View.

(ES-913-1) used at the radio transmitting station is generally similar to the studio equipment described above, except that the studio pick-up amplifier is replaced by a line amplifier inserted between the connecting wire line and the radio transmitter proper. While there is no provision for producing programmes at the radio transmitter station, nevertheless the amplifier equipment is arranged so that a microphone can be used for making emergency announcements. Figure 11 shows a typical equipment, including a spare amplifier and equalizer in the panel section at the right. The narrow intermediate section is a signalling panel manufactured locally and intended for use in conjunction with a special signalling system obtaining in all Japanese stations. The additional amplifying and signalling sections have been mounted in the common frame line-up for ease of control by the operator.

The method of operation between the studio and transmitter is so arranged that broadcasting is controlled from the studio. The preliminary adjustments are made by setting the volume in-

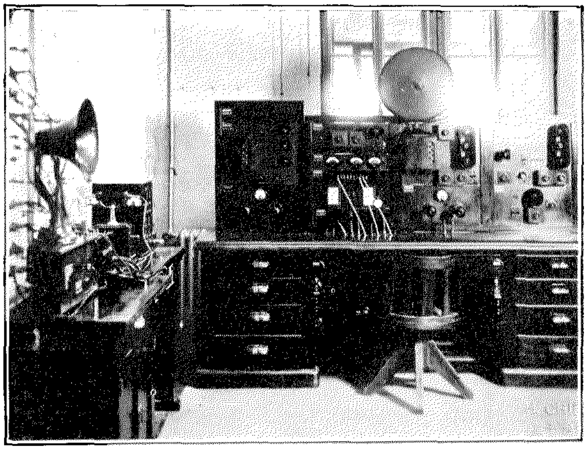

Figure 10—Speech Input Equipment.

dicator on the speech input equipment to an output energy of 2 decibels above reference level, or to the highest level possible without interference with the line. A steady tone is applied to the input of the speech amplifier and the amplitude of the tone is adjusted by the gain control potentiometers until a deflection of 30 divisions is obtained on the galvanometer. The steady tone is then transmitted to the radio transmitter via the line amplifier, and the gain control potentiometers on the line amplifier equipment are adjusted until the correct degree of modulation is obtained, as indicated by the modulator valve beginning to show grid current. The line amplifier adjustment is then complete and any necessary control of the programme is made directly by the studio operator. A permanent record of this adjustment is obtained by adjusting the volume indicator until the standard deflection of 30 divisions on the galvanometer is obtained, and making a note of the gain control and volume indicator settings.

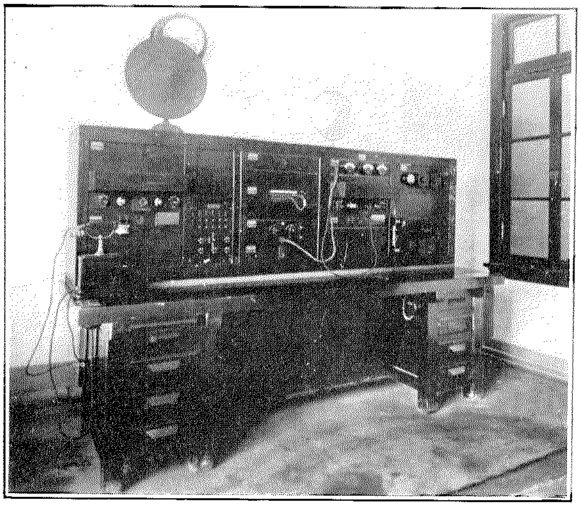

Figure 11—Line Amplifier Equipment.

Antenna

The antenna system at each station is somewhat different. Sapporo and Sendai have antenna of the simple T type, the former with two wires in the flat top and two parallel single lead-in wires and the latter with four wires in the flat top and a centre down lead. Each antenna has a natural wave length above the operating wave length, and series condensers are necessary for tuning; the overall resistance of each antenna is large, but the efficiency nevertheless is high because the radiation resistance is high. At both stations an insulated counterpoise has been installed, and at Sendai a buried earth system is also available. Counterpoise systems were installed at these stations because of the high resistance of the soil, especially at Sapporo, where the ground is frozen over for six months in the year; subsequent tests at Sendai, however, proved that under normal conditions the increase in resistance due to the earth system

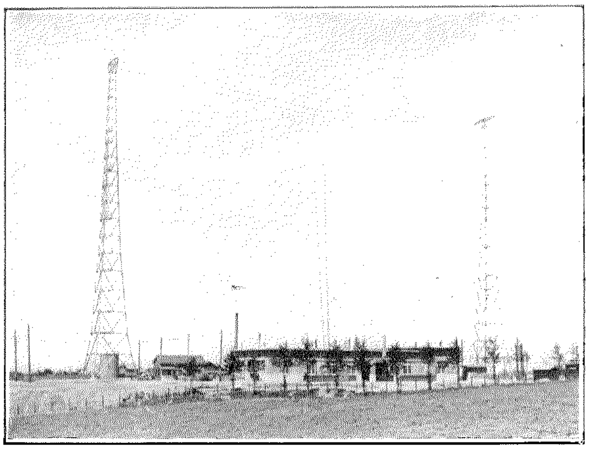

Figure 12—Sapporo Transmitting Station.

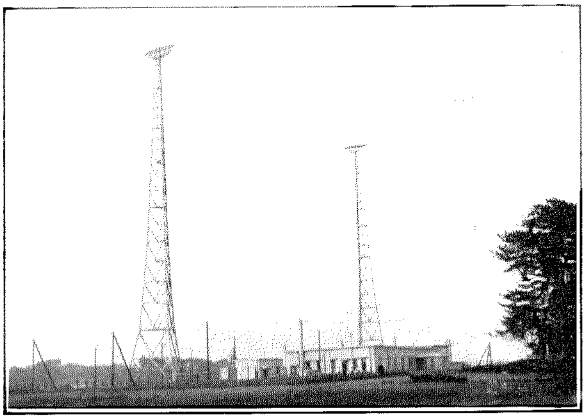

Figure 13—Sendai Transmitting Station.

is more than counterbalanced by the loss in effective height due to the counterpoise. Figures 12 and 13 give general views of the respective stations and antennae.

At Hiroshima station (Figure 14) the antenna is of the multiple tuned type with three down leads. The centre down lead forms the lead into the transmitter and is connected to the antenna tuning inductance. The outer leads are connected to earth via tuning coils similar to the tuning inductance. One of these coils, in its housing, is shown in Figure 15.

The data tabulated below include main dimensions of each antenna. The heights are those at the masts, with the height of the counterpoise deducted, but without allowance for dip.

Station	Operating Wavelength	Length Flat Top	Height Actual	Type
Sapporo	361.4	42.4	47.4	Simple T type Counterpoise earth
Sendai	389.6	42.4	52.4	Simple T type Counterpoise earth
Sendai	389.6	42.4	60	Simple T type Buried earth
Hiroshima	353	70	35	Multiple Tuned 3 down leads Buried earth

N. B.—*All measurements are in metres.*

Simultaneous Broadcasting

In connection with plans of the Japanese Broadcasting Association for transmitting programmes from the more important cities where better musical talent is available and for making announcements of a public and semi-public nature, the services of the Nippon Electric Company were enlisted to prepare plans for a trunking system suitable for linking up all of the Japanese broadcasting stations. This linking-up of stations was accomplished and the service made available during the period of the Coronation Ceremonies which took place in Tokyo and Kyoto beginning the 6th of November, 1928, and lasting for the greater part of the month. By this means, many of the details of these important ceremonies and also the associated programmes were broadcast simultaneously throughout the Empire.

Hokkaido, with its broadcasting station at Sapporo, had, unfortunately, to be left out of the general scheme on account of the strait, some 60 miles in extent, which separates it from the main land. Telegraph cables crossing the straits are in existence, also some telephone circuits, but they are not of the type suitable for broadcast purposes. However, most of the programmes were successfully broadcast from the Sapporo station by having first been picked up from Tokyo at 345 metres or from Sendai at 390 metres and re-broadcast on the Sapporo wave length of 361.4 metres. Due to the intense national interest in the coronation proceedings, the services performed by the broadcasting stations during this period were of the utmost importance and a source of great gratification to the broadcasting authorities and of satisfaction to the owners of receiving sets.

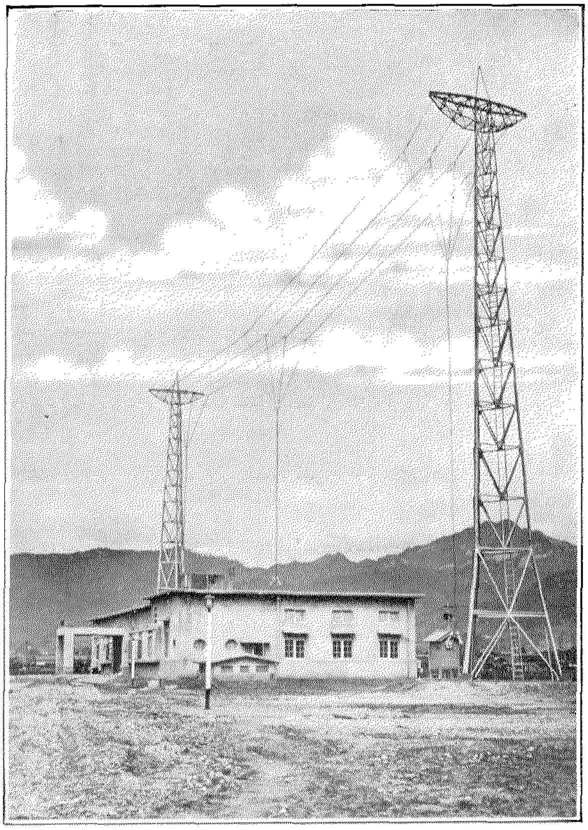

Figure 14—Hiroshima Transmitting Station.

Future Developments

Owing to the mountainous nature of the country, the signal strength from any station varies considerably with the locality, and there are a few large cities situated quite close to a broadcasting station where reception is very poor. Consequently, it is probable that the present main stations will be supplemented by small relay stations of two to three kilowatts capacity, provided there is sufficient demand for the service. It is probable also that the old one kilowatt transmitter at Nagoya will shortly be replaced by one of ten kilowatts, thus bringing it into line with the other high powered stations.

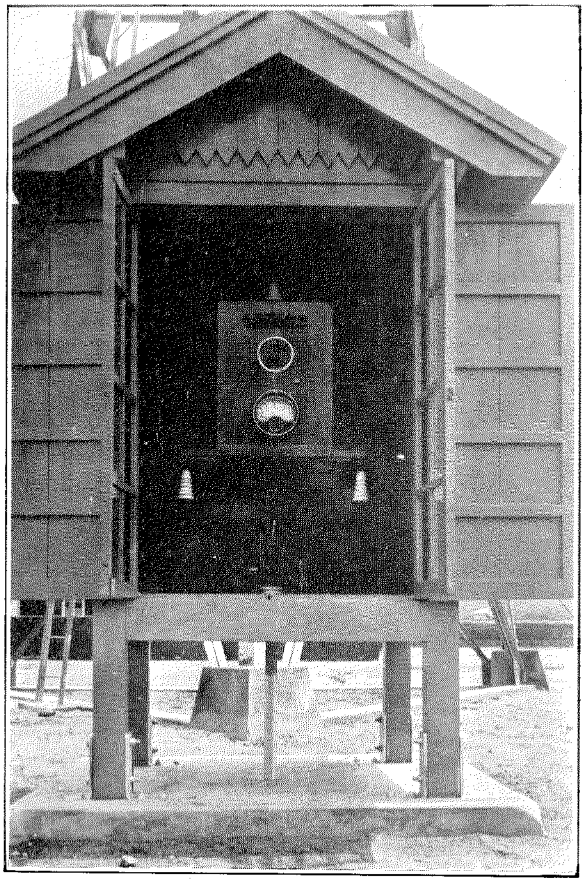

Figure 15—Antenna Tuning Coil and Housing.

High Efficiency Multiple Magneto Boards

By A. CAPEK

Bell Telephone Manufacturing Company, Antwerp

THE introduction of lamp signalling in the Local Battery (L. B.) system, coupled with the development of the Common Battery (C. B.) and Automatic systems, to a certain extent acted as a check on the intense development of magneto switchboards. Notwithstanding this competition from other systems, however, the magneto switchboard can still hold its ground in isolated or sparsely populated districts, or in territories where capital expenditure for a more expensive installation cannot be justified.

There are several reasons why this type of switchboard still remains popular with some operating companies. Its main asset, which remains always in evidence, is its simplicity, with the corresponding low cost, and easy and inexpensive maintenance. To this feature may be added the possibility of using the existing L. B. subscriber sets, which need not be replaced by other types. The transmission with L. B. subscriber sets is, furthermore, of high quality and independent of the length of the subscriber line so far as the talking battery supply is concerned.

The independent transmission battery supply, in connection with a hand-generator located in the subscriber set, makes it possible also to use longer subscriber lines, or lines of higher resistance (iron wire) than is advisable in any other system depending upon the central office for talking and signalling current.

Because of the wider operating limits obtainable through the location of the talking battery supply and the signalling generator in the subscriber premises, magneto boards are well adapted for successful operation even with a low grade line plant and are less affected by poor line insulation than are other systems with centralized power supply. This advantage is offset to some extent by the necessity for maintaining primary cells in the subscriber sets in good condition; but the high maintenance cost incurred thereby has been reduced to a considerable extent in the last few years through improvement in the manufacture of dry cells and the general introduction of motor transport for maintenance work.

Another advantage of the magneto boards—at least of those of the simpler type using drops instead of lamps and relays—is that they do not require any power plant, a few primary cells being sufficient to supply the operator's transmitter current. This merit has been of considerable value because, as a rule, magneto boards have been installed where power supply was not available.

The desire to operate magneto exchanges without central power plant caused delay in the introduction of new features, because these new features, involving as they did, new apparatus, mainly relays, would have meant the addition of central power plant.

This attitude of operating companies against the use of relays and lamps in magneto boards is now a thing of the past. The expansion in activity of the electricity supply companies in all countries, in conformity with the general use of accumulators for radio sets, overcame the hesitancy against power plants, and thus opened the way for improved L. B. systems.

The serious handicap to progress in this direction was removed just at the time when improvements in the C. B. boards brought a demand for operating improvements in magneto boards.

It should be understood that there is no tendency at the present time to incorporate in boards for magneto exchanges all the features adopted for the high-efficiency C. B. boards—even if this were possible. This would be going too far, and it would even destroy the most valuable feature of the magneto boards, *i. e.*, their simplicity and low first cost.

The problem facing the engineer resolves itself into selecting operating features such as will increase the efficiency of the magneto board as much as possible for minimum additional apparatus.

Investigation showed that it would be better to develop two different types of such boards—the first without and the second with toll preference facilities, in addition to some features common to both. These two types, known as the No. 2702-A and the No. 2703-A, respectively, are described herein, with the common and distinct features separated.

The 2702-A embodies bridging-type listening keys in the cord circuits with common ring-back and splitting keys in the operators' circuits, calling lamps associated with the multiple jacks, ring-back signal, automatic or manual metering and common party-line ringing keys.

The 2703-A type provides the same facilities and in addition gives flashing signals for toll preference calls, special busy tone on toll connections, automatic peg count, alarm signal in case of advance plugging, and cut-off keys for toll multiple lamps.

Reproductions of photographic views of the high efficiency magneto board are shown in Figures 1 to 4, inclusive.

(A) COMMON FEATURES.

The features selected for both types are as follows:

(a) *Bridging type of listening keys* for the cord circuits, with common ring-back and splitting keys (or also common monitoring keys) in the operator's positional circuit.

One of the much appreciated features of the magneto boards is the possibility of using the universal cord circuits both for local and for rural or toll connections. A standard magneto cord circuit does not meet all the requirements which a good toll cord circuit must fulfill as it does not contain splitting keys to enable the operator to disconnect a calling subscriber from her telephone set during the time she is preparing a toll connection. It also does not contain a monitoring key to enable the operator to listen-in on a toll connection without disturbing it.

In the magneto boards herein described, this deficiency is corrected in a very simple manner by using the bridging type of listening key. This key, in the operated condition, connects the two ends of a cord circuit to common apparatus in the positional circuit with the operator's telephone set in bridge, and does away with the need for apparatus individual to the cord circuit. By this means it is easy to provide not only common both-way splitting or monitoring keys, but if necessary, also common coin collecting keys. This arrangement makes it possible also to provide a common ring-back key per position and not individually for every cord circuit, as is required in the standard magneto board. The slight additional cost of the new cord circuit—due to the additional contact springs of the bridging listening keys, and to the new common monitoring and splitting keys—is more than balanced by the saving on the individual ringing keys. In effect, therefore, this additional feature of the high efficiency magneto board does not increase its cost, but makes it better adapted for universal service.

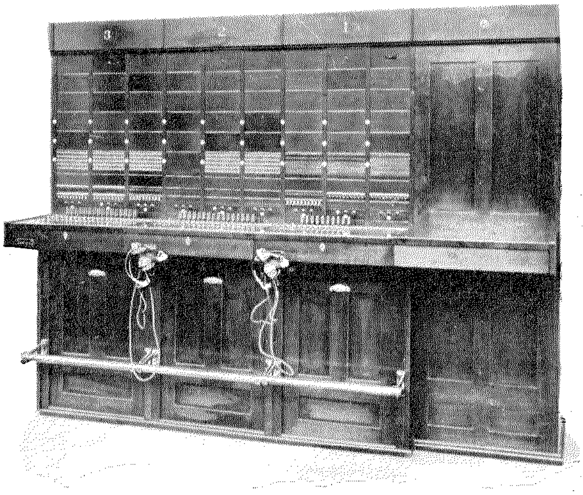
Figure 1—Front View of High Efficiency Magneto Board.

(b) *Multiple line lamps, associated with the multiple jacks.*

In a multiple line lamp system, all subscriber calls may be answered by any of the exchange operators. This circumstance reduces the waiting time and makes it possible also to increase the operator's load—especially in case of larger multiple boards, with their large team of operators, who are in a position to answer any call.

This higher operator's load therefore enables the operating company to save a certain percentage of operator's positions required for a given traffic. Furthermore, with boards of this type, the answering jack cable is not required, and the intermediate distributing frame is unnecessary. This feature simplifies the lay-out as well as the cabling and installation, and saves floor space at the same time. It also dispenses with the line pilot lamps which are usual with systems using separate answering jacks.

(c) *Operator's bar.* In case of multiple line lamps, it may happen that two operators try to answer a subscriber's call at the same time. It is therefore necessary to arrange the circuits in such a way that only one operator gets connected to the calling subscriber after the insertion of the plug and the throwing of the listening key, so that the second, or any subsequent operator who plugs in, remains disconnected and receives at the same time some sort of a warning signal as to what has happened.

It has been found possible to do this by means of only two common relays in the operator's circuit. This arrangement is used in the simple type high efficiency magneto board No. 2702-A, (Figure 5), which does not require any additional relays in the cord circuit to meet all the new requirements herein specified.

The second and more complicated type of the high efficiency magneto boards (No. 2703-A) constitutes another solution of this problem, making use of additional relays required for the toll break-down flashing feature peculiar to this type of board.

(d) *Ring-back signal* during the time the operator is ringing up the called subscriber. This feature is of considerable importance to the operator, as it eliminates most of the unnecessary re-calls on the part of the calling subscriber, who usually wishes to have his party rung again, if he does not get a prompt answer. The equipment needed for this purpose is really insignificant, as only a small condenser common to the position, in addition to some contacts in the ringing or listening keys, is required.

(e) *Automatic or manual metering.*

A special type of automatic operation of the subscriber's register may be provided with either of the two types of boards, if required. These meters count the total of all calls (including ineffective), and are operated automatically during the time the ringing keys are thrown. Since they lock as soon as they are operated, the successive re-rings cannot actuate them a second time.

In countries where this method of metering is used, it is customary to give the subscriber a certain discount on all the calls recorded in this way, (from 25% to 35%), to compensate for ineffective calls. This practice is very popular with the subscribers, and it saves a considerable amount of trouble to the operating companies.

If only effective calls are to be counted, it is necessary to operate manually in the well-known way, by means of meter keys associated with the cord circuits. Unless the L. B. subscriber sets are changed so as to enable the subscriber to give automatically a supervisory signal to the operator, it is not possible to let the subscriber meter automatically—that is, to have the meter energized as soon as the calling subscriber takes the receiver from the hook.

(f) *Adaptability of the boards for C.B. operation.* The subscriber's line circuit relays on these L. B. boards are so arranged that they may be changed later, if required, to C. B. operation, by simply re-strapping their soldering terminals. Furthermore, the cord circuit apparatus may be connected to terminal strips at the rear of the board, and the cord circuit relays can be placed on a separate rack to make a corresponding change possible with the sections.

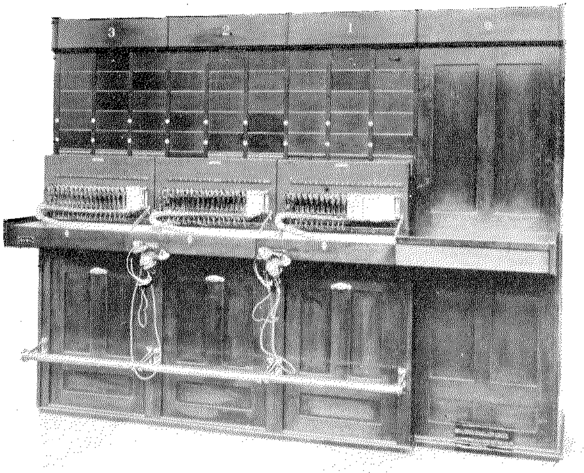

Figure 2—High Efficiency Magneto Switchboard—Key Shelves Raised.

(g) The cord circuit clearing-out lamp is extinguished by the operation of the listening key in the usual way.

(h) Common party-line ringing keys may be inserted in the positional circuit if required (they are shown only for the No. 2703-A board). These keys are to be operated in connection with the operated listening key.

(i) Ringing pilot relays with ringing pilot lamps are provided in both types of these high efficiency L. B. boards.

(B) DISTINCT FEATURES

The additional features applied to the more complete and more expensive board of the type No. 2703-A are the following:

(j) *Flashing signals for "toll preference calls."*

The positions are equipped with a common toll break-down key, which enables the operator to start a flashing signal at another position in case a local connection is to be broken down to give preference to a toll call. This signal appears on the supervisory lamp at the "local busy" position where the subscriber required for a toll connection is talking.

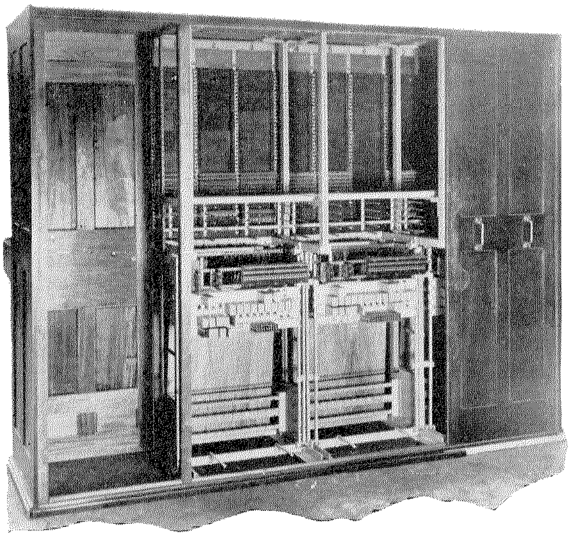

Figure 3—Rear View of High Efficiency Magneto Switchboard.

A toll call may be offered to the subscriber before breaking down the local connection, if the operating rules allow this practice ("toll offering").

(k) *Special busy tone on toll connections.*

If a subscriber is connected to a toll line, a "toll line busy" tone is applied to the sleeve conductor of his line, so that the operator may distinguish if the tested line is "local" or "toll busy." To make this possible, and still to keep the simple type of cord circuit for both local and toll service, it is necessary that the line circuits used for toll lines have their sleeve conductors connected to a common tone test coil.

(l) *Automatic peg count for both effective and ineffective calls.*

The counting takes place at the time that the subscriber's meter registers.

(m) *Alarm signal in case of "advance plugging."*

In a multiple line lamp board there is no reason for an operator to plug out a second call before she is through with the first one, as there are always other operators who may answer such a call more promptly. The 2703-A board is therefore arranged in such a way that if an operator plugs out a call, but does not answer it, *i. e.*, does not throw the listening key, the supervisory lamp flashes. This signal calls attention to overlapping calls, and helps to eliminate them.

(n) *The clearing out lamp is automatically extinguished* by the withdrawal of the answering plug, and does not require the prior operation of the listening key, as is the case with the 2702 type board

(o) *Cut-off keys for toll line multiple lamps.*

Such keys may be provided if required by the operating company, in case it is advisable that toll calls should be answered on some of the positions only.

CAPACITY OF THE SWITCHBOARDS

These boards are built in two sizes:

(1) A small type, with a low keyshelf (790 m/m from the floor) allowing the use of standard height chairs.

These boards are one-position three-panel sections with a capacity of 400 jacks and lamps per panel, *i. e.*, with a total capacity of 2,400 lines in case of a six-panel multiple.

(2) A larger type, with a high keyshelf (980 m/m from the floor) and necessitating the use of high chairs for operators.

These boards are also arranged for one-position and three-panels, and have a capacity of

600 pairs of jacks and lamps per panel, *i. e.*, a total capacity of 3,600 lines with a six-panel multiple, and 5,400 lines with a nine-panel multiple.

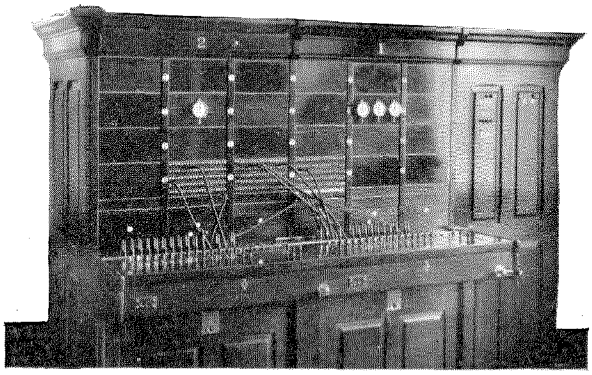

Figure 4—Another Front View of a High Efficiency Multiple Magneto Board.

In both types there is sufficient space at the bottom of the subscriber multiple field for toll or rural lines or for other miscellaneous circuits.

POWER PLANT

The current consumption for both types of high-efficiency magneto boards is very small; a three-minute conversation in the 2702-A type requires but 0.1 ampere-minute, and in the 2703-A board 0.4 ampere-minute. A small and inexpensive power plant is therefore sufficient. For example, a 500 line exchange with 10 three-minute calls per day, per subscriber, needs only 8.3 ampere-hours for 24 hours in case of 2702-A boards, and 33 ampere-hours with the 2703-A board.

Primary cells may be used for the 48 volt battery for the operation of the subscribers' service meters.

OPERATION OF THE 2702-A BOARD (CIRCUIT FIGURE 5)

(a) *Subscriber* (local, rural, or toll) calls and rings up the line relay LR, which operates and lights the multiple line lamps.

(b) *One of the operators answers* by inserting the plug AP and throwing listening key LK. This action splits the cord circuit, closes the sleeve circuit over relay COR and the common marginal relay ABR (both operate), and applies a busy test potential to the third conductor of the calling line. The message register MR will not meter because the potential available is not yet high enough.

The energized COR relay disconnects relay LR from the line, opens its locking winding and thus releases it, so that the multiple line lamps are extinguished.

The relay ABR pulls up over both windings in series, and locks over its low resistance, thus shunting its first winding.

The calling subscriber is now connected through to the operator and can give his order.

(c) *The operator tests* for "busy" with the CP plug in the usual way and the current flows, if the called line is occupied, from the tip of the plug over one of the 48,000 ohms resistances of the operator circuit to ground, thus changing the potential of the condenser C_1 and causing the usual click in the ear.

(d) *Operator plugs in* (connects) with plug CP if the line is free, and restores LK. The insertion of this plug makes the called line "busy" and energizes the COR relay of the called line in series with the resistance in the cord sleeve. The operator now throws the combined ringing and listening key in the ringing position, and ringing current is applied to the line from a hand generator, a pole changer or a ringing machine. The ringing pilot relay RPR is energized, if the circuit is not open, and the lamp RPL lights. At the same time, the meter of the calling subscriber is operated by a 48 volt potential applied to the sleeve conductor of his line, and holds over a second winding.

During the ringing period a part of the ringing current is sent back over the condenser C_4 to the calling subscriber, thus notifying him that his party is being rung, and obviating any unnecessary re-calls of the operator.

(e) *As soon as the called* subscriber answers, the conversation may start, but there is no further circuit change.

(f) *If the calling subscriber rings off* at the end of the conversation, the clearing out relay CR pulls up, locks over its holding winding, lights the clearing out lamp CL, and also the pilot lamp PL over the pilot relay.

(g) *The operator listens on the cord* in order to determine whether both subscribers have rung off. The throwing of the listening key opens the

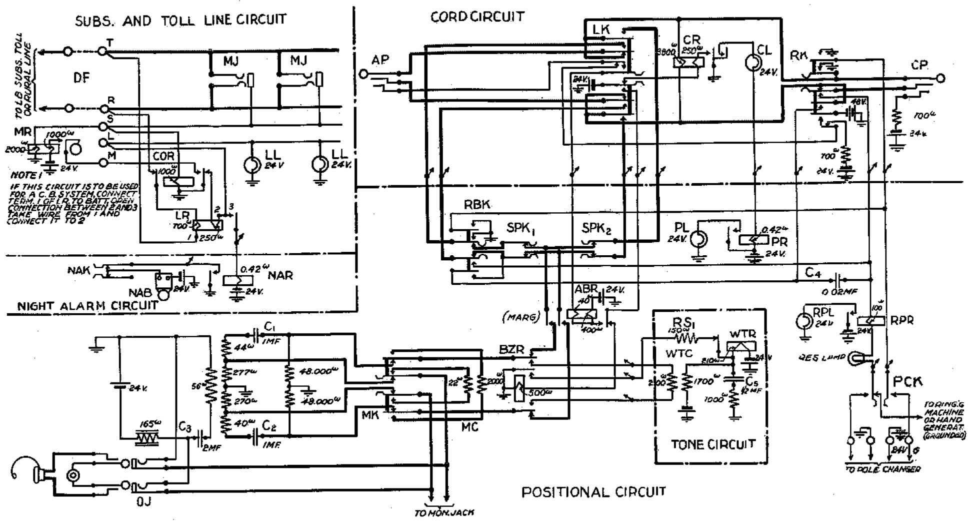

Figure 5—Circuits of No. 2702-A Board.

locking winding of relay CR so that it releases and the lamp CL is extinguished.

The operator takes the connection down and all apparatus returns to normal.

Special Cases

(h) *A second operator answers* a call, but is late. In this case the two windings (in series) of the relay ABR of this operator are shunted by the low resistance winding of the corresponding relay of the operator who answered more promptly, and it does not therefore pull up. However, a circuit is closed for the common relay BZR (over a contact of the operated listening key and a back contact of ABR) so that relay BZR is energized and a buzzer tone is connected to the operator's receiver, notifying the operator that the call has already been attended to.

(i) In case the operator finds the called line busy during the busy test she informs the calling subscriber of the fact, and takes out the answering plug.

(j) If the operator wishes to ring over the answering plug to call the local subscriber back for a rural or toll connection, or for some other reason, she throws the common ringing-back key RBK, taking care that the listening key of the particular cord circuit is in the operated position.

(k) If the operator wishes to talk with a subscriber without being heard by the other party, she throws the common splitting key to position SPK_1 or SPK_2 in addition to the listening key. This operation is, as a rule, required during the preparation of a toll connection.

(l) For monitoring purposes, the common monitoring key is operated. This key disconnects the operator's transmitter, and connects the receiver to the secondary winding of a special monitoring repeating coil. The operator is thus able to follow the conversation without making the line noisy and without impairing transmission.

Operation of the 2703-*A board* (*Circuit Figure* 6):

(a) Subscriber (local, rural, or toll) calls and rings up the line relay LR, which operates and lights the multiple line lamps.

(b) *One of the operators answers* by throwing listening key LK and inserting plug AP. This action splits the cord circuit, closes the sleeve circuit over relays COR and SR_1 (which operate) and applies a busy test potential to the third

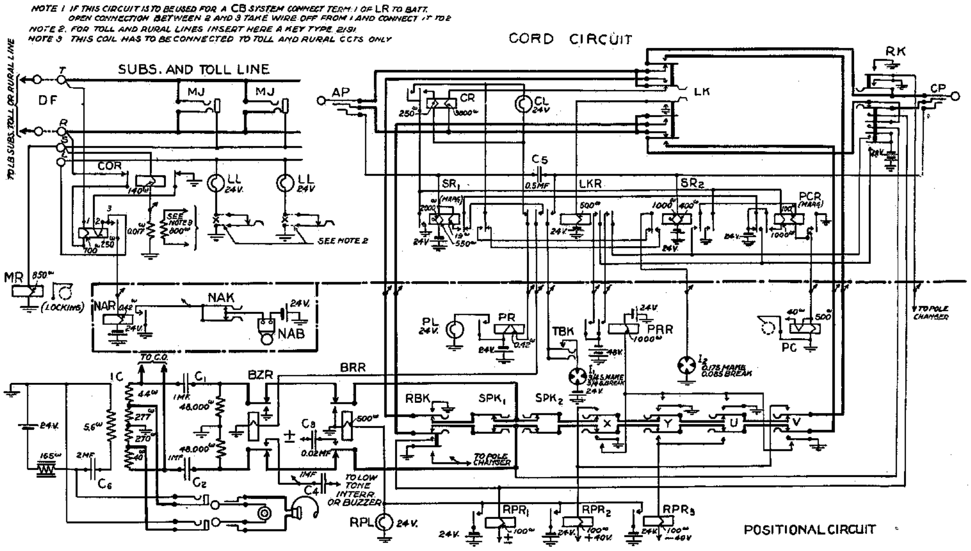
NOTE 1 IF THIS CIRCUIT IS TO BE USED FOR A CB SYSTEM CONNECT TERM. 1 OF LR TO BATT. OPEN CONNECTION BETWEEN 2 AND 3 TAKE WIRE OFF FROM 1 AND CONNECT IT TO 2
NOTE 2. FOR TOLL AND RURAL LINES INSERT HERE A KEY TYPE 2191
NOTE 3 THIS COIL HAS TO BE CONNECTED TO TOLL AND RURAL CCTS ONLY
TO LB SUBS. TOLL OR RURAL LINE
SUBS. AND TOLL LINE
DF
MJ
MJ
AP
CR
CL
CORD CIRCUIT
LK
RK
CP
COR
LL
LL
SEE NOTE 2
C5
SR1
LKR
SR2
PCR
MR
(LOCKING)
NAR
NAK
NAB
PL
PR
TBK
PRR
PC
TO POLE CHANGER
TO C.O.
IC
C1
BZR
BRR
C3
C2
C6
C4
TO LOW TONE INTERR. OR BUZZER
RBK
SPK1
SPK2
X
Y
U
V
TO POLE CHANGER
RPL
RPR1
RPR2
RPR3
POSITIONAL CIRCUIT

Figure 6—Circuits of No. 2703-A Board.

conductor of the calling line. The message register MR will not meter, because the current available is not yet large enough. The energized COR relay disconnects relay LR from the line, opens its locking winding, and thus releases it, so that the multiple line lamps are extinguished.

Relay SR_1 operates over its high resistance winding, and locks over its low resistance winding, thus shunting it. The listening relay LKR is also energized.

The calling subscriber is now connected through to the operator and can give his order.

(c) *The Operator tests* for "busy" with the CP plug in the usual way and current flows, if the called line is busy, from the tip of the plug over one of the 48,000 ohms resistances of the operator circuit to ground, thus changing the potential of the condenser C_1 and causing the usual click in the ear.

(d) *Operator plugs in* (connects) with plug CP. The insertion of this plug makes the called line "busy" and energizes the sleeve relay SR_2 in series with the COR relay of the called line, thus disconnecting the LR relay.

If the operator restores LK and now operates the combined ringing and listening key in the ringing position, the ringing current is sent over the line, and the peg count meter PC operates. As soon as its armature is attracted, a low resistance shunt is placed across its high resistance winding, which increases the current in the circuit, so that relay PCR operates. This relay locks itself and disconnects the peg count meter.

The operation of the ringing key also places a 48 volt potential on the line message register MR over a front contact of relay PCR and over the low resistance winding of relay SR_1. The meter operates and is held operated until the connection is taken down at the end of the conversation.

As long as the ringing key is thrown, the ringing pilot relay RPR_1 is energized and the lamp RP is illuminated. At the same time relay BRR is in the operated position, and a part of the ringing current is sent back over condenser C_3, to the calling subscriber, thus notifying him that his party is being rung and obviating any unnecessary recalls of the operator.

NOTE: In case of party-line ringing, one of the keys X, Y, U, or V is depressed (with listening key thrown), in which case the relay PRR operates. This relay applies 48 volt potential to the peg count, as well as to the subscriber meter of the calling line, which are both energized in the same way as if only the single party ringing key RK is thrown. During the operating of one of the party line ringing keys, either RPR_2 or RPR_3 relay operates, and with it also relay BRR, and ringback signal is sent again to the calling subscriber over the contacts of the listening key.

(e) *As soon as the called* subscriber answers, the conversation may start.

(f) *If the calling subscriber rings off* at the end of the conversation, the clearing out relay CR operates and locks over its holding winding, and lights the clearing out lamp CL, as well as the pilot lamp PL over the pilot relay PR.

(g) *Operator now takes down* the connection, and this action releases the COR relay as well as relays SR_1 and SR_2. The relay SR_1 opens the locking winding of relays CR and PCR which both release and extinguish lamp CL. The operator may of course listen in on the connection before taking it down, to be sure that the conversation is really finished. The operation of the listening key in this case also extinguishes the clearing-out lamp.

SPECIAL CASES

(h) *A second operator answers* a call but is late. In this case the high resistance winding of the relay SR_1 of this cord is shunted by the low resistance winding of the SR_1 relay of the first operator, so that it does not operate. But relay LKR is energized and closes a circuit for the common relay BZR so that it operates also, and connects a tone to the operator's receiver, notifying the operator that the call has been attended to.

(i) In case the operator finds the called line "busy" (during the "busy" test) she informs the calling subscriber of this fact, and takes the answering plug out.

(j) If the operator wishes to ring back over the answering cord to re-call the subscriber in case of toll calls, etc., she depresses the RBK key with listening key thrown.

(k) If the operator wishes to talk with a subscriber without being heard by the other party she throws the common splitting key to position SPK_1 or SPK_2 in addition to the listening key. This operation as a rule is required during the preparation of a toll connection.

(l) If a subscriber is connected to a toll line, a special "toll busy test" is applied to this sleeve conductor from the sleeve of the particular toll line over the cord circuit sleeve and the condenser C_5. The operator testing for "busy" on such a "toll busy" line, will therefore recognize this special "busy" condition, and will know that she cannot break such a connection for another preference call.

(m) If the operator preparing a toll connection finds the wanted local subscriber "busy" on a local call, and wishes to break it down, she inserts the calling plug in the multiple jack of his line, operates the common splitting key SPK_1 (leaving the listening key thrown) and informs the local subscribers that the conversation will be broken for a toll connection. Thereafter she momentarily operates the toll breakdown key TBK. This places 24 volt potential over an interrupter on the sleeve of the CP plug, and short circuits intermittently the relay SR_2 of the associated cord circuit, as well as the SR_2 or SR_1 relays of the local cord circuit on which the wanted subscriber is "local busy."

The repeated release and operation of relay SR_2 in the "home" cord circuit remains without any influence as long as the listening key is thrown but the similar operation of relays SR_1 or SR_2 in the "local busy" cord circuit produces an interrupted flash of the CL lamp with pilot lamp PL and thus notifies the local operator that one of the subscribers connected up is required for a toll connection.

The "local busy" operator then takes down the local connection.

NOTE: The operator may, of course, offer a toll call to the subscriber, who is talking locally, if the operating rules allow this practice. In this case, she talks with him over the connecting plug CP, and if the subscriber agrees to take the toll call, she operates the break-down key in the same way as just described, and flashes in this way the distant operator.

(n) If an operator plugs out a second calling lamp during the time she is attending to the first one (so called "advanced plugging") and does not throw the listening key, the CL lamp starts to flash with cord pilot lamp PL over the energized SR_1 relay.

Automatic Telephony in the Zürich Area

By E. WOLLNER

Bell Telephone Manufacturing Company, Antwerp

ZÜRICH was satisfactorily served for about thirty years by the Magneto Telephone System supplied by the Bell Telephone Manufacturing Company. Not until 1917, when the Swiss Administration decided to rearrange the grouping of the subscribers in this area, was it found necessary to provide more modern facilities. The Administration then introduced the Rotary Automatic System.[1] The number of subscribers was at that time increasing steadily. The population was over 200,000, and provision had to be made for future growth. Moreover, it was thought desirable to bring some of the more prosperous suburbs, such as Hoengg, Wollishofen, Altstetten, Oerlikon and Tiefenbrunnen, into closer relationship with the city. It was thereupon decided to form from the main city exchanges two twin-unit exchanges, i. e., Hottingen-Limmat and Selnau-Uto, and to provide five sub-offices for those suburbs.

The first in this series of automatic exchanges, i. e., the Hottingen office, began with the semi-automatic system, but three years after its inauguration, it was converted to full automatic working. Each of the exchanges now operates on a full automatic basis. A separate exchange was built for the accommodation of the equipment necessary for the toll service.

In the main exchanges, where two installations are accommodated in one building, a certain part of the equipment—i. e., the various distributing frames, the testing and monitoring apparatus and power plant—is common to both.

Traffic to and from the satellites, Wollishofen and Altstetten, is directed through the Uto main exchange. Traffic to and from Oerlikon and Tiefenbrunnen is directed over the Limmat main exchange. The fifth satellite, Hoengg, is served by the Hottingen office. The present and ultimate capacity of the five offices and satellites, and the numbering scheme of the subscribers, are given in Table I.

The following is a short description of the various exchange equipments, and of some special circuits introduced to satisfy certain service requirements.

Equipment of Hottingen-Limmat Main Exchanges

Since 1920, when the Hottingen office was converted to full automatic operation, this twin-unit exchange has utilised the standard features of the Rotary Automatic System. Figure 1 is a schematic of the more important exchange equipment. The equipment is divided into three principal groups. The switches belonging to one of the groups serve the Limmat subscribers, those of the second group, the Hottingen subscribers, and the third group comprises equipment common to both of the exchanges. The Hottingen switching equipment is located on the third floor of the exchange building, the ground floor of the same building being occupied by the Limmat equipment.

The upper part of Figure 1 shows how, in the Hottingen exchange, one group of switches serves for communications with the other exchanges, and for the satellites. It shows the junctions from the Hoengg satellite connected to the arc of the second line finder. Junctions incoming from the other main exchanges are connected to the brushes of the second group selector. For outgoing traffic, distinction must be made between calls destined for Hoengg subscribers and those for the other main exchanges. The junctions outgoing to Hoengg are connected to the arc of the third group selector; those for the main exchanges to the arc of the first group selector.

The lower part of the same figure shows the interconnection of the various switches in the Limmat office. These correspond to the arrangement made for the Hottingen exchange with the exception that the junctions from two other satellites, namely, from Oerlikon and Tiefenbrunnen, are here connected to the arcs of the second line finders.

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[1] G. Deakin, "No. 7-A Machine Switching System," *Electrical Communication*, Vol. III, No. 3, January, 1925.

The equipment which serves for both the main exchanges is seen in the middle of Figure 1. This common equipment is not located centrally, but a part of it is installed on the second floor, and another part on the third floor of the building. It consists of the following parts:

One common distributing frame serves for the termination of the subscribers' lines and junction lines. It will be noted from Figure 1 that, whereas a separate intermediate distributing frame is provided for the Hottingen exchange, no such frame is provided in the Limmat exchange,where the latest method of cross connecting without a special frame is already employed, i. e., on the top of the final switchrack, terminal strips are mounted for cross connecting purposes, and the associated jumper wires are run through special rings. This arrangement effects economy in cabling, installation costs, and floor space. In the Limmat exchange, the switchboard side of the main distributing frame is cabled direct to the final terminals on the top of the switchracks, and not via the intermediate distributing frame as in the Hottingen exchange.

One desk is provided for testing purposes. Here, the lines coming from the test finals of both exchanges end in test jacks. In addition to this common equipment, a two-position outjunction test and monitoring desk is provided for the Limmat exchange. The junctions outgoing from the Limmat exchange are tested on this desk, where, in addition, false calls are dealt with, and register guard-lamp circuits indicate hold-ups on the registers.

Equipment of the Selnau-Uto Main Exchange

In the second of the twin-unit exchanges in the Zürich Area the latest design and arrangement of apparatus has been installed, and since no restriction was made as regards accommodation and no consideration of existing plant was necessary, the exchange was laid out in conformity with the latest practice.

A description of the exchange equipment has already been published by Mr. P. Schild,[2]

TABLE I

MAIN EXCHANGES

	Normal lines installed	P. B. X. Lines	2-Party Lines	Total of installed lines	Ultimate capacity	Numbering
Selnau	7447	1624	4	9075	8000	S1000—S9999
Uto					4000	U1000—U3999
Hottingen	8527	341	132	9000	9600	H1000—H9599
Limmat	1323	125	40	1488	3000	L1000—L3999

SATELLITES

Hoengg	218	2	—	220	300	H9600—H9899
Wollishofen	467	15	—	482	550	U4000—U4549
Altstetten	239	2	—	241	350	U5000—U5349
Oerlikon	466	23	90	579	600	L8000—L8599
Tiefenbrunnen	560	13	52	625	700	L9000—L9699
Total	19247	2145	318	21710	27100	

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[2] *Bulletin Technique de l'Administration des Télégraphes et des Téléphones Suisse*, Année V. No. 4.

giving details of the apparatus employed and the location of the various racks.

Figure 2 represents the junction diagram of the exchanges. The upper and lower parts show connections of the Selnau and Uto switches, respectively. The middle part indicates the equipment common to both exchanges.

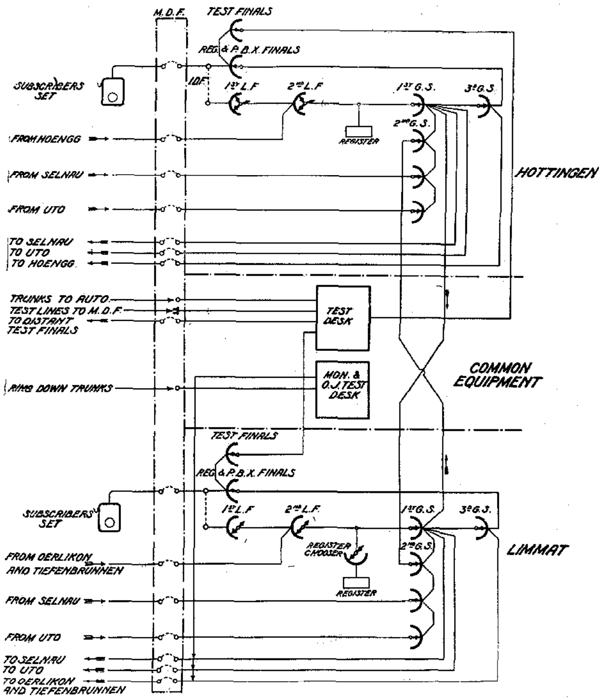


Figure 1—Junction Diagram of Hottingen-Limmat Main Exchanges.

Both of these exchanges employ the same type of equipment, the only difference being that in conjunction with the Uto office two satellites—Altstetten and Wollishofen operate—but no satellite is connected to the Selnau office.

The connection of the subscribers with other exchanges and satellites is accomplished in the same manner as explained for the other main offices. The switchracks and the service observation desks are located on the second floor of the building. The main distributing frame, the message register bays and wire-chief's desk occupy the first floor. It was necessary to provide a certain amount of common equipment which could not have been conveniently divided between the two exchanges—for example, the main distributing frame and the desk equipment.

The service observation desk is provided for observing calls originating at the exchange. For this purpose a panel of jacks, equipped with one jack for each first line finder, is mounted on the end of the line finder switchrack. Each jack is wired into the circuit between the first and second line finder. A further group of jacks, wired to the service observation desk, is mounted below the panel of line finder jacks, the groups being multiplied. Thus, by means of patching cords any line finder jack can be connected to any jack in the other group, and placed under observation; or, in a similar manner, a group of line finders may be observed.

The equipment of this observation desk contains, in addition to the observation circuits, means for verifying the number dialled by the subscriber. It also contains jacks connected to idle terminals in various line finder groups, to enable the attendant to make what are termed "spy calls." This equipment allows the Administration officials to collect data concerning the quality of the service offered, at various periods of the day.

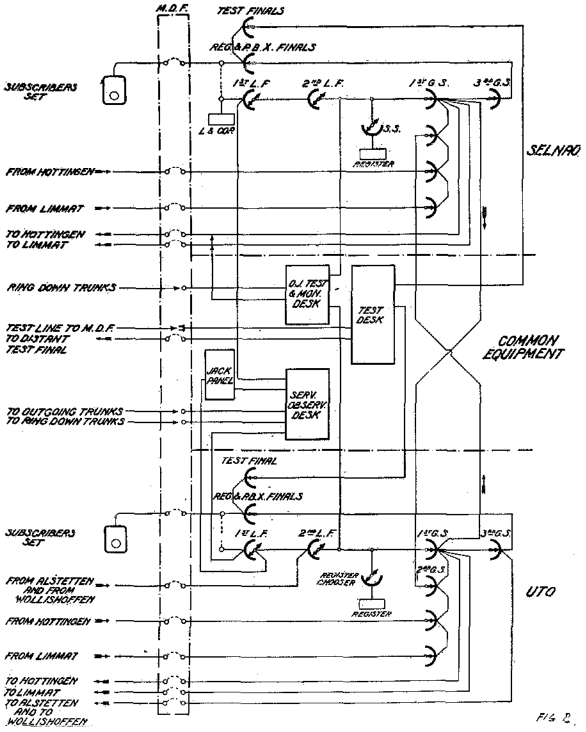


Figure 2—Junction Diagram of Selnau-Uto Main Exchange

The wire-chief's desk, which is also common to both exchanges, is located close to the main distribution frame. This desk is provided with the necessary jacks for outgoing, incoming and ringdown trunks, together with jacks connected to the brushes of the test finals. Voltmeter and telephone circuits enable the wire-chief to carry out the necessary tests.

Equipment of the Satellite Exchanges

The switching arrangements in each of the five satellite exchanges are, with small deviations, the same. Figure 3 is a typical junction diagram of one of the satellites. It will be seen that incoming calls from the main exchanges are directed over a trunk terminating at a final selector in the satellite exchange. The outgoing calls to the main exchange, of which the satellite forms a sub-group, are established in the same way as for subscribers connected to the main exchanges, with the difference that only a certain number of the switches are located in the satellite. As indicated in Figure 3, the outgoing trunks are connected to the brushes of the first line finder at one end. They terminate at the other end on the arc of the second line finder in the main exchange.

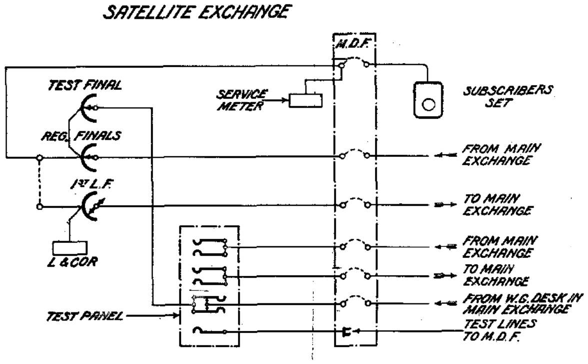


Figure 3—Junction Diagram of a Satellite Exchange.

In addition to the finals serving each group of 200 subscribers, one test final is included per final group at each of the satellite offices. By means of these special test finals, the wire-chiefs at the main exchanges may test the internal and the external equipment associated with any satellite-subscriber's line. The circuit also provides facilities whereby the test final selectors may be set to a line on any level and then stepped round by means of a stepping key to any of the remaining lines on that level. This feature proved to be valuable for routine testing.

In addition to the above, a small test panel equipped with voltmeter testing circuit, lines to main frame, etc., is provided for each of the satellite exchanges. This panel is essentially designed for carrying out routine testing at the satellite exchange or for testing on lines terminating at the main frame, but not jumpered to the exchange equipment.

One group of final selectors is arranged to give facilities for the connection of P. B. X. trunks and for hunting over groups of trunks.

No separate intermediate frames are employed in the satellite exchanges, all cross connections and distribution of the lines over the groups of line finders being done on the switchracks.

The line finders have a capacity of 100 lines per arc and are mounted on bays, together with the associated circuit relays and line and cut-off relays for that particular group of 100 lines. The line finders and relays are then connected by means of a local cable to the terminal strips at the top of each bay. These terminal strips correspond to those normally equipped on the vertical, or "answering," side of an intermediate distributing frame (I. D. F.). In a similar manner, terminal strips are mounted on the top of the final selector bays. These terminal strips correspond to the horizontal, or "multiple," terminal strips of the I. D. F. The cross connections are made by triple jumper wire between the terminal strips of final selectors and the terminal strips of the line finders of the switchrack.

This scheme offers maximum economy in cabling, since in addition to the fact that no intermediate frame or line relay racks are required, the runs of the switchboard cable from I. D. F. to line finders, I. D. F. to final selectors, and I. D. F. to line and cut-off relays, are now replaced by simple local cable forms on the switchracks.

Power Plant Equipment

Each of the twin-unit main exchanges has a common power plant. The original power plant of the Hottingen exchange was designed for use with the semi-automatic working of the exchange. At the time the exchange was converted to full automatic operation, the power plant underwent some modifications. The battery voltage was raised from 24 volts to 48 volts, and the "ringing tone" was introduced, i. e., provision was made in the power plant to give an audible signal to indicate to the calling subscriber that the called party was being rung.

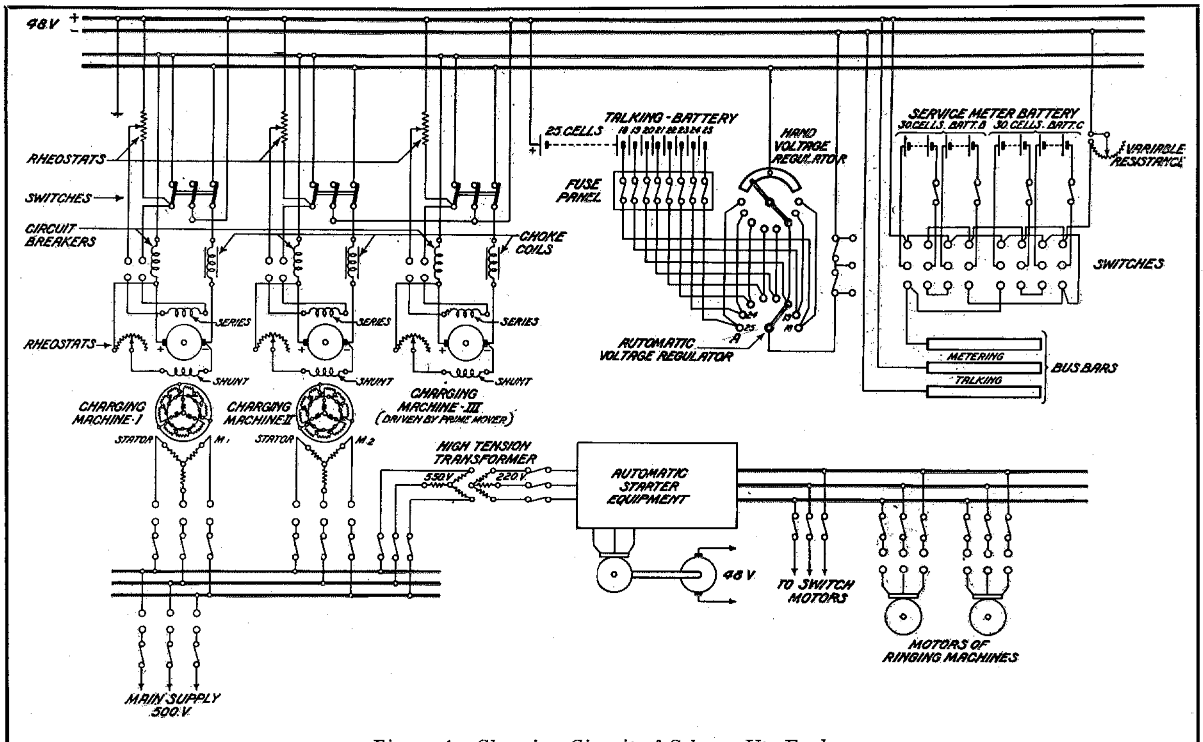


Figure 4—Charging Circuit of Selnau-Uto Exchange.

The power plant supplied for the Selnau-Uto exchange is more nearly typical of modern installations. Figure 4 shows the fundamental charging circuit, the auxiliary circuits being omitted for the sake of simplicity. One main storage battery is provided for both of the exchange current-drains. If the exchanges grow beyond the capacity for which they were planned, this battery may be supplemented by a second battery of suitable size. The battery consists of 25 cells, the last cells being used as end cells for the regulation of the voltage. Two voltage regulating end cell switches are provided, one hand-operated switch in the charging machine circuit and one automatically-operated regulating switch in the exchange load circuit; the former is used to prevent the end cells, which are rarely used, from being continually overcharged.

The automatic switch in the discharge circuit maintains the voltage at the bus-bars at 48±2 volts. For the operation of the message registers, a separate battery (with a duplicate as reserve), consisting of 30 cells, is connected to the 48 volt bus-bars in such a way that there are obtained at the message register bars about 100 volts, the value required for the satisfactory operation of the message registers.

Two 30 KW telephone generators of the combined compound and shunt wound type were supplied as charging sets, and are driven by two A. C. motors. Normally, they will be operated with the compound connection. The series winding is, however, brought out to a switch mounted on the machines so that it can be cut out to enable the machines to be operated shunt-wound when it is necessary to boost up the voltage for overcharging the battery. The floating system of charging is used, and the charging sets are of sufficient size to give a complete charge to the storage battery in nine hours.

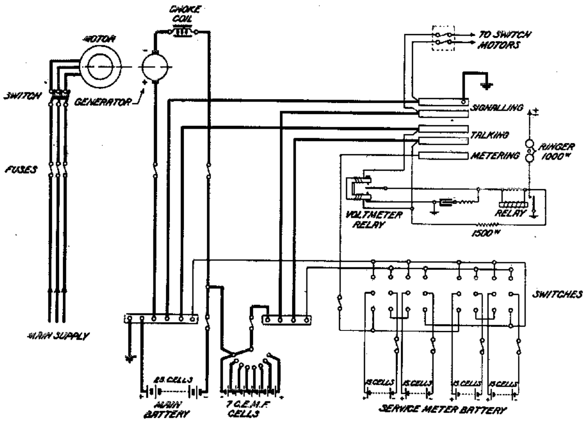


Figure 5—Power Circuit for Hoengg, Oerlikon and Tiefenbrunnen Satellites.

The two ringing machines are driven from the outside power supply; should this supply fail, the battery driven reserve set can be automatically cut into service.

An emergency charging unit, consisting of a benzine engine and a charging generator, is also provided. The corresponding charging generator has a capacity sufficient to charge the battery and at the same time to provide the current required for switch motors, ringing machines, and a 3 KW drain for the emergency lighting circuit.

The scheme chosen for the power supply of the satellite exchanges is somewhat different. The power circuit used in the Hoengg, Oerlikon and Tiefenbrunnen satellites is different from that employed for the Wollishofen and Altstetten satellites. The power plant for the first three satellites mentioned is indicated in Figure 5, and consists of a single battery of 25 cells in series with a set of 7 counter-e. m. f. (C. E. M. F.) cells for maintaining the exchange voltage between the required limits of 44 to 52 volts. The capacity of the batteries in the individual satellites is chosen so that they would give a reserve of two to three days if the exchange were fully equipped. Two small storage batteries, each consisting of 30 cells in series, are furnished for supplying the booster voltage for metering. As the current required for this purpose is extremely small and is only applied for a fraction of a second, batteries of very small capacity are sufficient. One motor generator consisting of a 3-phase induction motor directly coupled to a 6 KW charging generator serves as a charging set. As the battery reserve is such that a charge is sufficient for several days, one motor-generator set is sufficient.

Ringing current is furnished by a special combined ringing machine and switch motor which also serves to drive the automatic switching equipment. A voltmeter relay is connected between the two talking battery bus-bars. In the event of the voltage exceeding or falling short of predetermined values, the voltmeter closes one of its contacts and completes an alarm circuit which results in an audible signal being given to the attendant.

In the Wollishofen and Altstetten satellites, an unattended type of power plant is working. Since the traffic in both of these satellites is approximately the same, their power plant is of equal size and practically identical, except as regards slight differences due to the outside power supply. The power plant consists of the same components as mentioned in connection with the other three satellite exchanges, but the circuit is so arranged that the motor of the charging set is automatically started and stopped.

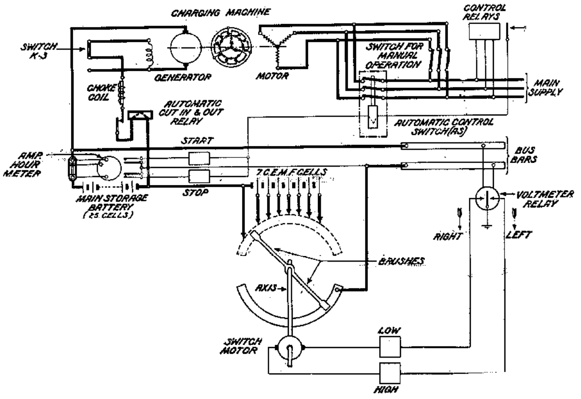


Figure 6—Power Circuit for Wollishofen and Altstetten Satellites.

Figure 6 shows the power circuit of these satellites. Its characteristic feature is that it can be left unattended for a long time during which any trouble that may arise is signalled automatically to the attended main exchanges. The illustration shows the fundamental charging circuit, but the auxiliary circuits which secure the automatic regulation of the machines are omitted.

The following functions are carried out automatically:

(a) Every time one of the contacts of the voltmeter relay is closed, C. E. M. F. cells are cut in or cut out, as the case may be, in order to keep the voltage at the bus-bars as close to 48 volts as possible. This is done by a switch motor which drives the automatic voltage regulating switch in clockwise or anti-clockwise direction, according to the closing of contact Left or Right of the voltmeter relay.

(b) When all the C. E. M. F. cells are cut out, or the ampere-hour meter indicates that the battery requires recharging, the charging motor is automatically started, and the charging circuit is closed. In this case, the contacts on the ampere-hour meter serve for the closing of the circuits of the starting and stopping relays.

(c) When all C. E. M. F. cells are cut in and the ampere-hour meter indicates full charge of the battery, the charging circuit is opened and the charging generator is stopped.

Toll Switching Equipment

The toll office equipment is installed in a separate building. It was therefore necessary to provide for special services for subscribers wishing to avail themselves of long distance communication.

At the time the Hottingen semi-automatic local exchange was converted into full automatic working, the Swiss Administration decided to introduce automatic toll switching between all local offices and the toll office. At present, every subscriber of the Zürich area can be called up automatically from the toll exchange. In the same way every subscriber can reach the recording, information, and other boards of the toll exchange by dialling the proper number.

As regards the outgoing calls from a toll operator to one of the local exchanges, it is evident that direct automatic calling from the toll board has brought many advantages, since the entire toll connection is thereby placed under the control of the toll operator.

Figure 7 shows the various routes employed for setting up a toll switching connection. The complete trunk circuit, including link circuit and register apparatus, are mounted in the toll exchange, whereas the apparatus for the group selector and final selector circuits are located in the automatic local exchanges.

The switching apparatus employed in the circuit comprises:

(a) 100 point finders as jack finders, trunk finders, and register choosers.

(b) A group selector with 300 junction arc capacity, i. e., 30 junctions on each of the 10 levels. This selector is arranged to select twice, and then to hunt.

(c) A final selector with capacity of 200 lines.

The sequence switches used are of the horizontal type and all the switches are driven by means of flexible gears.

The register consists of a combination of relays which record the number chosen at the toll position, and controls the setting of the selectors used for completing the connection in accordance with the number recorded.

If a main exchange subscriber wants a toll connection, he dials 14, which connects his set with the recording position in the toll office as indicated in Figure 8. The same types of switches are engaged as in the case of an ordinary call, and in addition a set of relays is provided to connect alternating ringing current to the trunk line which leads to the recording position. This current actuates the positional line relays in the usual way.

The call originated by a satellite subscriber is routed in the same way as an ordinary call. Every subscriber, in addition to requesting toll calls, can make use of the other special services previously mentioned.

Special Circuit Features

Transmission Circuit. The connection circuit which serves for local conversations is of the high resistance bridge impedance type with 48 volts talking battery. The transmission circuit between two local subscribers is shown in Figure 9. The circuit is fed over the windings of the Asr and Csr relays. At six different points of the

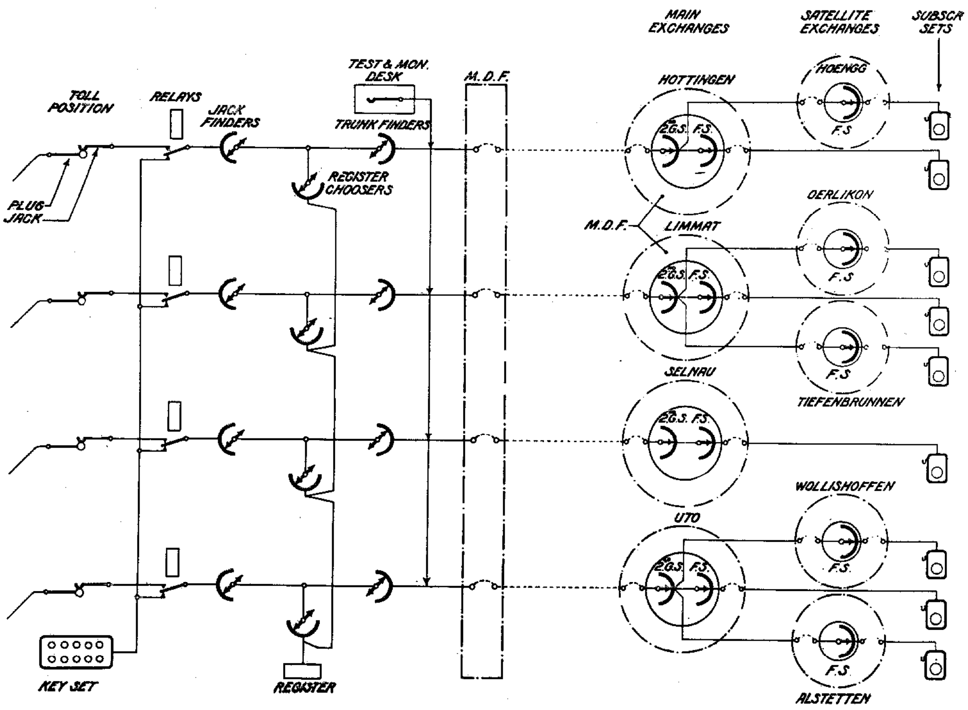


Figure 7—Toll Switching Connections.

circuit, test jacks are provided to enable the maintenance staff to test the various sections of the circuit.

Metering. The 7-A Rotary System is particularly well provided for as regards measured service. The service meter circuit is so designed that it cannot be operated by a fault. To show the method of operation of the meters, a part of Figure 9 is extended in more detail in Figure 10. It will be noted that during the whole conversation a circuit is closed over relays COR and Ler and cam I, so that relay COR attracts its armature and cuts off the line relay Lr; furthermore, Ler, by closing its contacts, connects the 48-volt talking battery to the subscriber's set. As soon as the conversation is ended and the subscriber replaces his receiver, sequence switch contact I is opened, whereas, contact X is closed. Consequently, the meter battery of 55 volts is connected in series with the 48-volt battery shown at the meter windings. The increased potential operates the meter, and in this way all successful calls are registered.

Toll Switching. When the question of introducing automatic toll switching into the Zürich Area arose, it was essential to consider a system which would not involve radical changes in the already existing toll exchange. The circuit in Figure 11 fulfills this requirement. Every toll position is equipped with a 10-button key-set, by means of which the operator may call any of the local subscribers by depressing the subscriber's number on her key-set one digit at a time. The digits may be depressed in succession as fast as the operator can work. Figure 11 shows somewhat in detail how the transmission from toll manual to automatic switching is solved, and how the jack finder (Figure 7) is started when the toll cord is inserted in the jack of one of the outgoing junction lines. The closing of jack contact A actuates relay Fsr, which in turn closes the Asr relay circuit. The latter relay provides a circuit in which a group of jack finders commences to hunt for the jack circuit. The link circuit is thus set up and the circuit is extended to the final selector to which the called subscriber is connected in the manner indicated in Figure 7.

During the progress of the switching operations, the toll operator is able to supervise continually the building up of the circuit until the subscriber answers the call. The supervisory signals which are given to the operator are as follows:

Plug inserted in the jack.	Supervisory lamp out.
Link circuit established.	Supervisory lamp burns.
Register circuit established.	Key pilot lamp (KPL) burns.
Hunting trunk to final.	Supervisory lamp flickers intermittently and key pilot lamp out.
All finals busy.	Supervisory lamp burns.
Selection finished.	Supervisory lamp flickers.

The final selector is now on the wanted line, but does not test it until the operator gives a short ring.

During the succeeding operation, the following signals are given:

Line free.	Supervisory lamp burns.
Line busy.	Supervisory lamp flickers.

When the line is free, the toll operator calls the subscriber in the normal way. When the subscriber answers, the supervisory lamp signal disappears, and when, after conversation, the subscriber replaces his talking set, the lamp burns again as a sign that the operator can disconnect.

False Calls. To eliminate loss of time, and to make the switching apparatus as efficient as possible, arrangements are made so that if any subscriber inadvertently dials the number of a non-existent line, he is notified. Figure 12 shows the circuit employed when the number of a dead line is dialled by one of the subscribers.

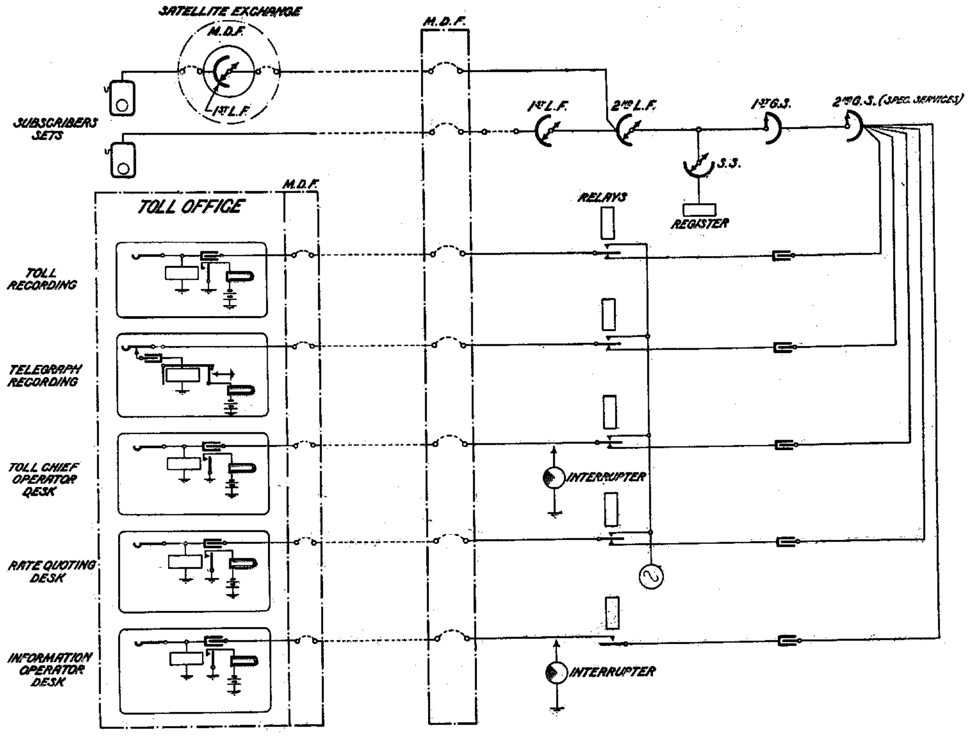


Figure 8—Toll Connections.

When this circuit is seized by a final selector, relay Trr is energised over the ground on the A-wire (see sequence contact X) and locks over its right-hand contact. The left-hand contact serves for the excitation of the relay Twr (the corresponding circuit runs over the test relay). The relay Twr locks and lights the calling lamp LL before the operator. The inner left-hand contact of relay Twr provides a ringing tone to the calling subscriber until the operator answers. When the operator inserts the plug, for the purpose of advising the subscriber about the false call made, the relay Slr operates over the sleeve circuit.

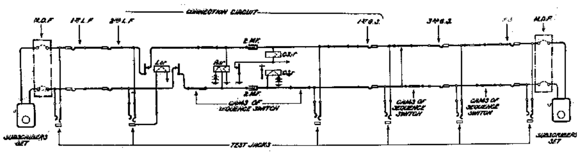


Figure 9—Transmission Circuit between Two Local Subscribers

A similar arrangement is made in the case of a call ending in a dead level of the first group selector.

Permanent Glow. Permanent line loops or incompleted calls are handled in the following manner: When an interval of 30 seconds elapses before the first digit is dialled into a register, or a similar interval elapses between the dialling of any two consecutive digits, the cord circuit provides for the immediate release of the register and the flashing of a lamp signal on the monitoring desk. Jack equipment (PGJ) on the desk gives the operator direct access to the line concerned. A simple voltmeter test circuit is supplied with the monitoring desk to allow the operator to make a preliminary investigation of the cause of the trouble, and "howling" may be applied where necessary. Figure 13 shows the arrangement in its broad outline. An earth condition is transmitted from a timing device in the register to operate relay Pgr. Relay Pgr operating, drives the R sequence switch to the talking position, while, at the same time, the release of the register circuit is effected.

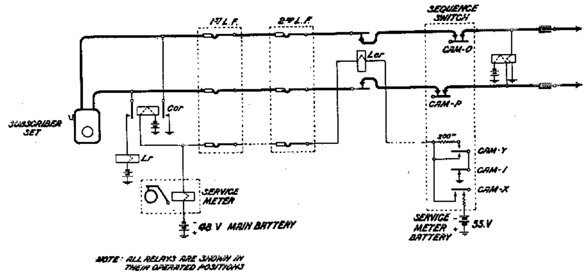


Figure 10—Metering Circuit.

The PGL (permanent glow lamp) circuit is closed and opened intermittently through interrupter No. 1, causing the lamp to flash.

In the event of the lamp signal remaining unattended, the timing switch TA in the connection circuit, after a predetermined length of time, will automatically disconnect interrupter No. 1, and close the lamp circuit through interrupter No. 2, thereby producing flashes of greater frequency.

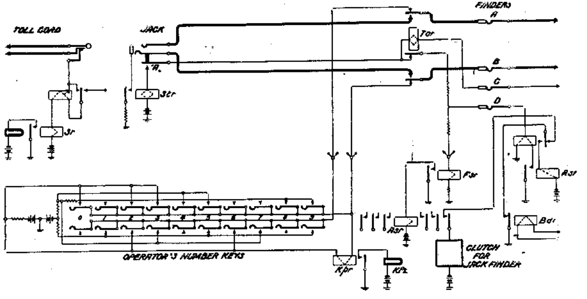


Figure 11—Automatic Toll Switching Circuit.

Hold-over. If a subscriber has dialled all the digits, and the selection is not completely set up, the subscriber's line is automatically released but the connection circuit is held, and the register and all subsequent selectors remain in their last operated positions to facilitate the tracing of the fault.

It will be seen from Figure 13, that the relay Pgr is energised from the time-switch TA at the register, which, if all digits have been registered, will cause relay Shr to operate. As relay Pgr is energised, the operation of relay Shr opens the third wire and releases relay Ler, thus setting free the calling subscriber's line.

An alarm and lamp CIL indicate to the fault-

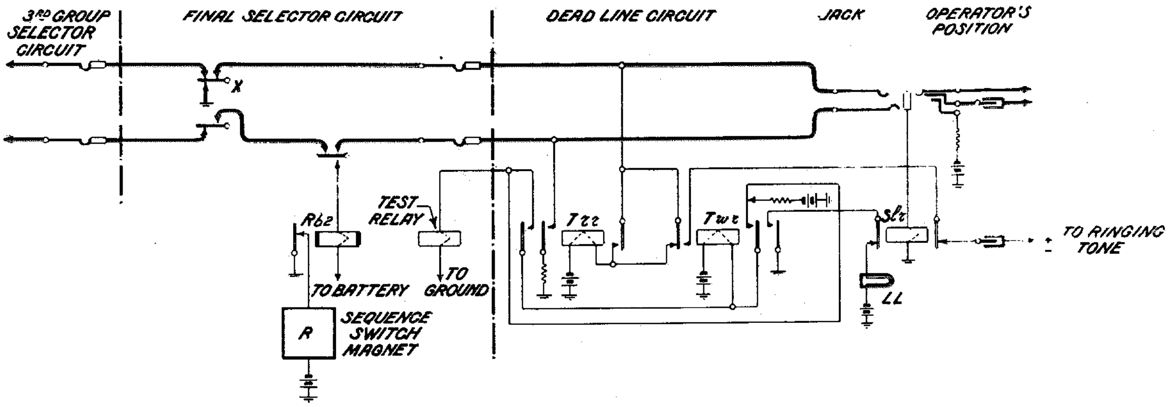


Figure 12—Dead Line Connection.

man the existence of the "hold-over" condition. Meanwhile, the subscriber is free to pick up another connection circuit and to recommence dialling.

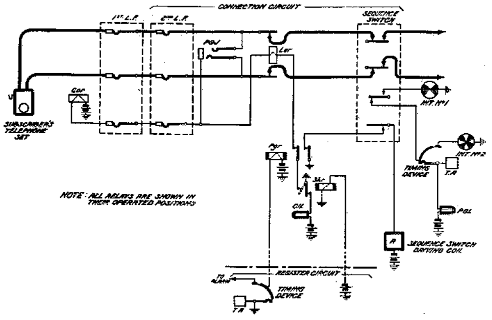
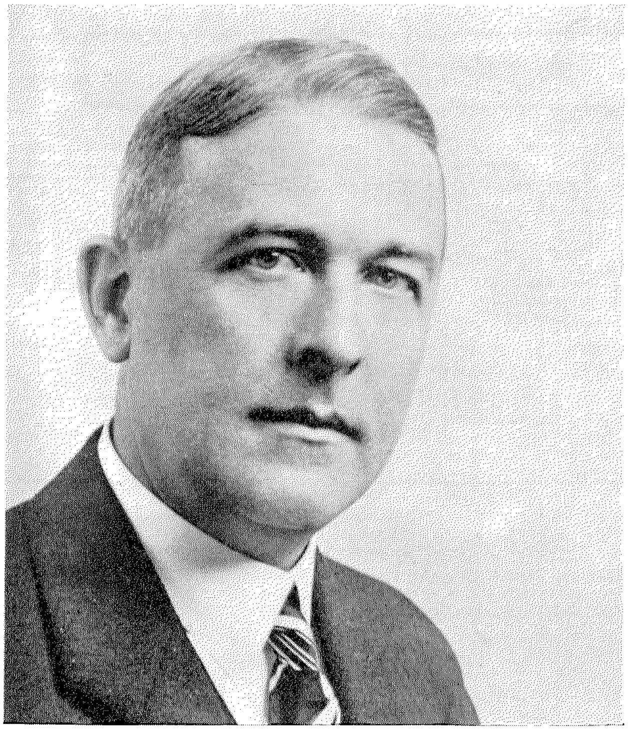


Figure 13—Circuit of Hold-over Feature.

Conclusion

The equipment described was supplied for the Zürich Area for the purpose of establishing automatic telephone communication between the local subscribers on the one hand, and the local subscribers and the toll office on the other; also, for bringing the whole telephone traffic in that area on to a uniform basis. The programme which the Administration had planned at the time of the introduction of the automatic service has proved to be correct and is confirmed by the results achieved.



Edward Beech Craft, Executive Vice-President of the Bell Telephone Laboratories, died at his home in Hackensack, N. J., on August 20th, after an association of over a quarter of a century with the Bell System.

In 1926, on the occasion of his receiving the degree of Doctor of Engineering from Worcester Polytechnic Institute, he was styled:

> Engineer, Inventor and Organizer of Research; whose inventions take part daily in each of more than fifty million telephone conversations; whose genius, initial conception of the practicability of panel systems for machine switching, and continued supervision of its development have contributed largely to the present system of telephony; whose technical experience devoted to the service of his country during the World War hastened advances in radio-communication with aircraft; whose organizing ability continuously applied for a quarter of a century to engineering development and industrial research has increased the social and economic significance of research.

In addition to his ability as an Engineer, Inventor and Organizer, Mr. Craft possessed unusual enthusiasm and charm of personality which made him many loyal friends, among whom are officers, directors and employees of the International System.

The Aluminium Electrolytic Condenser

By **R. E. W. Maddison, B.Sc., Ph.D. (Lond.)**

Of the European Installation Department, International Standard Electric Corporation[1].

INTRODUCTION

Anodic Polarization

If the voltage of an electrolytic cell or an electrode immersed in an electrolyte is altered by some cause from its equilibrium value, it is said to be polarized; anodically if it is made more positive than the equilibrium value; cathodically if more negative. Polarization may be produced by impressing an external voltage on the electrodes of the cell; it may result from concentration changes in the electrolyte, or from some intereference with the main electrode reaction itself, as, for example, the production of a non-conducting film on the electrode surface.

When a metal dissolves anodically, producing metal ions capable of combining with the ions of the electrolyte to give a sparingly soluble substance, further solution of the metal may be hindered as a result of the deposition of a film on the electrode surface. The presence of the film reduces the area of the electrode in contact with the electrolyte, and consequently increases the current density on the parts not affected. An increased polarization is then necessary to maintain a given current, and the electrode reaction may be modified. In those cases where the electrode surface is completely covered by such a film, exceedingly high polarizations may occur.

The physical properties of the film, such as its porosity, thickness, electrical conductivity, and so on, vary in different cases. It is upon the formation of badly conducting films at the surface of a metal anode, permitting the maintenance of high voltages between the electrode and the electrolyte, and preventing the discharge of anions (the passage of any appreciable current), and the relative stability of the anode film when made a cathode, that the production of electrolytic condensers and rectifiers is rendered commercially possible.

The characteristic property of the anode film upon which its rectifying property depends is that of unidirectional current conductance. When the electrode is made positive, the current passing is very small after the film has formed; but on reversing polarity, current conduction is possible. The film, therefore, can act as a valve, and by suitable arrangements of electrodes bearing these films rectification of alternating currents is possible. The film also exhibits a very high electrostatic capacity, which property is utilized for the production of static condensers.

Although this valve action has been observed with most metals under suitable conditions, only two, namely aluminium and tantalum, have gained wide use commercially for rectifiers. For condensers, aluminium alone would appear to have found application.

Theories of Electrolytic Valve Action

The various theories that have been advanced to explain the unidirectional current-flow characteristic and the dielectric properties of anode films may be divided into two classes:—

1. The Gas Film Theory,
2. The Solid Film Theory,

according as the active layer responsible for the phenomena is considered to be gaseous or solid. Although a visible oxide film is present on a formed anode (*e. g.* aluminium), it is certain that this visible layer is not the active one, but that another inner film is formed that is responsible for the behaviour of the electrode.

1. *The Gas Film Theory.*

K. E. Guthe (7) ascribed the high resistance of the aluminium anode to the presence of a thin film of oxygen gas covering the electrode, preventing the passage of negative ions from the electrolyte to the electrode. He likened the film produced on the electrode surface to a

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[1] Communicated by Rollo Appleyard to the *Philosophical Magazine*, and published in Vol. VIII, July, 1929. Permission to reprint from the *Philosophical Magazine* is gratefully acknowledged.

semipermeable membrane, allowing only certain ions to pass through it and to discharge. The behaviour of an ordinary copper ferrocyanide semipermeable membrane was compared with that of an aluminium anode, and found to be similar. It was observed that a high resistance was present when current was passed from a copper to a platinum electrode immersed in an electrolyte, the two electrodes being separated from each other by the semipermeable membrane; in the reverse direction the resistance was very low.

The gas film theory has been supported in particular by A. Günther-Schulze (23, 24, 28), who considers that during the formation period of the valve metals there are produced simultaneously two films:

(*a*) an inactive solid oxide film,
(*b*) an active gas film.

The solid film is not responsible for the rectifying or condenser properties of the electrode, but serves to hold in position the oxygen gas film, which has the properties of a dielectric. The pores of the oxide layer, in so far as they are not occupied by gas, are filled by electrolyte. Electrons from the metal electrode can cross the gas film, but electrolytic ions from the electrolyte are unable to do so.

In extending Günther-Schulze's hypothesis, A. H. Taylor (33) considers the gas film to be held between an aluminium hydroxide layer and the aluminium electrode: the gas in contact with the aluminium surface combines partially with the metal to give a thin film of aluminium oxide.

2. *The Solid Film Theory.*

The rectifying and condenser properties of the aluminium anode have been ascribed by other workers (11, 14, 16, 34, 37, 38) to the presence of a solid film acting as

(*a*) a Wehnelt interrupter,
(*b*) an ohmic resistance,
(*c*) a true dielectric,
(*d*) a semipermeable membrane.

J. Slepian (30), in his contribution to the solid film theory, has applied the principle of thermionic rectification to explain the operation of thin films such as occur in electrolytic and other rectifiers.

He considers the gas film theory of rectification to be untenable on the following grounds. A gas film has a low dielectric constant (a little over unity), so that it is difficult to account for a sufficient lowering of the work function to permit electron emission from a metal surface at ordinary temperatures; the work function for the escape of electrolytic ions from an aqueous solution should be less than in the case of electrons escaping from a metal surface; lastly, electronic conduction may be imparted to the electrolyte without in any way destroying the rectifying properties of the film. He prefers to ascribe the behaviour of a valve anode to the solid film covering the electrode surface. In the case of aluminium the film is thought to consist of a transition or dehydration product of aluminium hydroxide produced during the forming period. This film has insulating properties in consequence of the almost complete lack of free electrons, exactly as in the case of a vacuum. Electron emission from the metal electrode into the insulating film is controlled by a work function as in the case from a metal to a vacuum. As a result of the definite time required for electrons to traverse the film from one electrode to the other, space-charge effects may arise, and thereby reduce the current flow to a very small value.

The dielectric constant of the film will also influence the work function. The extent of the attraction exerted by the dielectric on the electrons escaping from the metal surface will depend on whether the work function forces are operative within or without the dielectric layer. Assuming a dielectric constant of 13, the work function may be reduced to from 1/13 to 1/7 of its value for vacuum. In view of the fact that the electron emission is approximately proportional to the work function, it follows that it is possible for electron emission to take place at ordinary temperatures into a film of dielectric constant ca. 13, and that the electric field necessary to enable electrons to overcome the work function will be correspondingly reduced.

The above outline has assumed a uniform distribution of the dielectric film over the surface of the electrode. Seeing that the forces of the work function are operative through a distance of ca. 10^{-8} cm., which is of the order of atomic dimensions, this would mean that the film is discontinuous. It is possible that even in the case where the film is formed or built up on the electrode itself, the work function is suppressed at some points and is operative at others: electrons will pass from the metal to the film only at certain discrete points. By combining a favourably polarizable junction surface with one that is non-polarizable, we obtain an asymmetric arrangement which will exhibit the unidirectional current flow characteristic upon which the production of electrolytic rectifiers and condensers is dependent.

F. M. Gentry (6) has established mathematically that the electronic conduction in unidirectional current conducting non-metallic films follows essentially the same law as that found for electronic conduction in an evacuated space. Satisfactory agreement was obtained between calculated and observed values for the current passed at various voltages by the film of an aluminium electrolytic condenser (see pp. 228 and 230 of discussion to (29)).

In connexion with the solid layer theory, it is interesting to note that a condenser with a solid dielectric (calcium fluoride), and analogous to the electrolytic type of condenser, has been prepared (18). A metal filament covered with a layer of the salt is fused into a glass vessel, the walls of which are locally covered with a metal coating. The vessel is highly evacuated, the filament is heated to vaporize the salt layer, and finally the filament is heated to a higher temperature in order to volatilize it and deposit it on the salt layer. The dielectric is 100–150 molecules thick, and has a breakdown voltage of ca. 10^8 V./cm. Particulars of the capacity of this condenser, as well as other electrical properties, do not appear to be available.

W. W. Taylor and T. K. H. Inglis (34) found that the essential peculiarities of an aluminium anode could be reproduced by means of a platinum anode having a film of aluminium hydroxide deposited upon it. This film acts as a semipermeable membrane in permitting the diffusion through it of certain salts, but not others (*v. infra*). A. Rouban (22) followed up this work, using a copper ferrocyanide semipermeable membrane (*cf.* Guthe *supra*; see also (35)).
Phil. Mag. S. 7. Vol. 8. No. 48. *July, 1929.*

It may be mentioned that A. L. Fitch (5) proposed the theory of a double dielectric, consisting of a gas and a solid layer, to account for the behaviour of the aluminium anode.

Formation of the Anode Film

In considering the various experimental data, reference will be made almost entirely to aluminium, and occasionally to tantalum, as it is these metals that have been most studied in connexion with their use for rectifiers and condensers.

When one of the so-called valve metals is made an anode in an electrolyte, the voltage necessary to maintain a given current density increases almost proportionally with the time of closed circuit. At a certain voltage partial breakdown, and at a still higher voltage complete breakdown, of the film occurs. This period of polarization is referred to as the "formation" period.

Formation of the dielectric film can take place on D.C. or A.C. The film which first appears on aluminium is transparent and colourless, but as its thickness increases, interference colours become visible, and after usage it appears greyish, due to the increased thickness of the film. The current density at a given voltage and frequency has considerable influence on the time of formation of the film. The greater the current density (small surface area) the more rapid the formation. The following figures obtained by H. D. Holler and J. P. Schrodt (9) are of great interest in this connexion. The application of 25 V.D.C. to an area of 1 cm.^{2} of aluminium anode gave almost instant formation, the current being reduced nearly to zero in 3 seconds. With an area of 300 cm.^{2} the formation was so slow that even with an applied voltage of 120 V. D.C. several hours were necessary to effect complete formation. Using A.C. under similar conditions to those just described, the time required for formation was about five times as great. The formation is also influenced by the composition of the electrolyte and the temperature.

Anodically treated aluminium heated *in vacuo* to 1200° C. evolves a negligible amount of gas, from which it is concluded (32) that the anode film consists of aluminium oxide and not hydroxide. This is interesting in connexion with Slepian's theory (*v. supra*) regarding the nature of the active layer.

Thickness of the Active Layer

It has been mentioned above that a distinction has to be made between the visible oxide layer and the inner active layer. The thickness of the active layer has been determined by measurements of electrostatic capacity (making the assumption that the dielectric constant is unity), by estimation from interference colours exhibited by the film, and by chemical analysis. The last two methods assume that the entire thickness of the film on the electrode is effective as a dielectric. Capacity measurements give results of a different order of magnitude from other methods of determination. (For a summary of the various values see [1].) Capacity measurement gives values of the order of 10^{-6} cm. for aluminium formed at 100 V.: other methods give values of $20\text{–}100 \times 10^{-6}$ cm. This discrepancy, and the fact that the thickness determined by capacity measurements is practically independent of the electrolyte, suggests that the film produced on aluminium consists of two layers. According to Günther-Schulze [28], the thickness of the active layer is dependent on

(*a*) the metal employed,
(*b*) the applied voltage;

and is independent of

(*a*) the electrolyte for aqueous solutions,
(*b*) the temperature,
(*c*) the method of formation.

TABLE I.

Voltage.	Relative thickness δ/ϵ.	
	Aluminium.	Tantalum.
50	6·4	4·1
100	10·3	7·1
150	16·1	11·6
200	22·3	17·0
250	29·3	22·9
300	37·1	28·8
350	46·6	34·6
400	58·0	40·3
450	71·0	45·0
500	85·9	49·1

δ = absolute thickness.
ϵ = dielectric constant.

Table I. shows the relative thickness

$$\frac{\text{absolute thickness}}{\text{dielectric thickness}} = \frac{\delta}{\varepsilon}$$

of the active layer formed on aluminium and tantalum at various voltages, assuming a dielectric constant of unity. Determinations of the thickness of the active layer depending upon capacity measurements are subject to the effect of frequency (*v. infra*), though at a given frequency the electrostatic capacity is a function of the applied voltage; this capacity is taken as being a measure of the thickness of the active layer.

Resistance of the Active Layer.

The high resistance of the anode film has been ascribed to the development of a counter E.M.F., but the evidence mainly indicates that the resistance is of an ohmic nature. It depends not only on the thickness of the active layer, but also on the applied voltage [26]. From the figures given in Table II. it is seen that during the formation period the current flow decreases at a quicker rate than the thickness of the active layer increases, so that the resistance of the active layer at constant voltage with decreasing forming current very rapidly increases. Tantalum was chosen to obtain the results given in Table II., since with this metal results are not obscured by the incomplete insolubility of the metal in the electrolyte, as in the case of aluminium.

TABLE II.

Time.	Forming current. i mA.	Cell voltage. e volts.	Thickness of		$\frac{e}{i}=r$ ohms.	$\frac{r}{\delta}$ ohms/$\mu\mu$.
			Solid layer. $\mu\mu$.	Active layer. δ. $\mu\mu$.		
10″	100	27	113	2·50		
30	100	73	160	3·53		
40	100	101·3	270	6·00	$1{\cdot}01 \times 10^3$	$0{\cdot}17 \times 10^3$
55	11	101·3	300	6·62	9·22	1·39
90	4·1	101·3	305	6·74	24·7	3·67
2′	3·1	101·3	307	6·78	32·7	4·82
10	1·16	101·3	325	7·17	87·2	12·2
60	0·54	101·3	335	7·39	188	25·5
260	0·37	101·3	350	7·72	278	36·0
450	0·25	101·3	355	7·82	413	52·8
2880	0·11	101·3	360	7·93	922	116
7340	0·07	101·3	390	8·60	1450	169
8780	0·06	101·3	395	8·72	1582	181

12·5 cm.^{2} tantalum in 0·05 N. KNO_3.
Formed at 100 V. D.C. Temperature 20° C.

The figures for the resistance of the active layer given in Tables II. and III. show that the discharge of an electrolytic condenser takes place slower than it would if it possessed constant ohmic resistance. The time of discharge is greater the greater the period allowed for charging, since e/i is greater, although the corresponding change in the electrostatic capacity (thickness of film) is much less. The figures given in Table III. must be taken as showing the general trend of the voltage-resistance characteristic, since individual values are dependent on the time elapsing between successive readings, and whether increasing or decreasing potentials are being applied ([26]).

TABLE III.

Voltage.	Aluminium. $\frac{e}{i}=r$ ohms.	Voltage.	Tantalum. $\frac{e}{i}=r$ ohms.
350	$2{\cdot}2\times10^4$	200	$0{\cdot}21\times10^6$
300	3·8	180	0·52
250	4·0	160	1·10
200	4·0	140	1·88
150	5·3	120	2·40
100	9·5	120	2·94
50	28·0	80	3·80
25	90·0	60	4·28
	*	40	5·00
			†

* 1000 cm.^{2} of aluminium in ammonium borate solution. Formed at 350 V. D.C. ([29]).

† 12·5 cm.^{2} of tantalum in 0·05 N. borax solution. Formed for one day at 200 V. D.C. ([26]).

W. R. Mott ([16]) gives the specific resistance of the film formed on aluminium in phosphate and sulphate solutions as 10×10^{10} ohms/c.c. and $0{\cdot}8\times10^{10}$ ohms/c.c., respectively at 25°C., the resistance decreasing as a logarithmic function of temperature. W. E. Meserve ([12]) computes the specific resistance of the solid layer to be 3.4 x 10^{12} ohms/c.c., assuming the layer to consist of Al_2O_3.

Table IV. gives figures showing the current-voltage characteristic for a formed aluminium electrode in ammonium borate solution ([29]). At constant voltage the D.C. leakage of an electrolytic condenser decreases with time. The D.C. leakage of a film subjected to a potential less than the forming voltage is of the order of a microamp./cm.^{2}. Schulze ([28]) gives a figure of $0{\cdot}15\times10^{-6}$ amp./cm.^{2} for aluminium formed at 110 V. in ammonium borate solution. The leakage current is considerably increased when corrosion of the electrodes takes place, and may increase 20–30 times. The product of corrosion by accumulating between the plates may even cause short circuit by deforming the plates and making them touch. The leakage current increases also with increase of temperature, as shown by the figures given in Table V. (Bairsto and Mercer ([1]). The current-temperature curve is an exponential one, $i=A\varepsilon^{at}$. For the figures given in Table V. $i=2{\cdot}04\varepsilon^{0{\cdot}085t}$. The constant "A" appears to be independent of the electrolyte, and dependent on the time of formation; "*a*," on the other hand, appears to be independent of the time of formation, and dependent on the electrolyte: thus

TABLE IV.

Voltage. D.C.	Current density. Amp./1000 cm.^{2}
− 6	0·8
− 5	0·4
− 4	0·1
− 2	—
+ 40	0·0001
+ 80	0·0005
+120	0·0015
+160	0·003
+200	0·005
+240	0·006
+280	0·007
+320	0·009

Aluminium formed in ammonium borate solution at 350 V. D.C.

TABLE V.

Temperature. t° C.	mA./cm.^{2}. i.	Ohms/cm.^{2}.
15	0·0075	$13{\cdot}3\times10^6$
30	0·025	4·0
40	0·059	1·60
50	0·186	0·54
60	0·375	0·27
70	0·600	0·17
75	0·757	0·13

Aluminium formed in ammonium borate solution at 105 V. D.C. for 140 hours. Tests at 100 V. D.C.

Electrolyte.	Time of formation.	
	8 hours.	140 hours.
Ammonium molybdate	$i=3{\cdot}55\epsilon^{0{\cdot}064t}$	$i=2{\cdot}04\epsilon^{0{\cdot}062}$
Ammonium borate	$i=3{\cdot}55\epsilon^{0{\cdot}085t}$	$i=2{\cdot}04\epsilon^{0{\cdot}085t}$

Dielectric Strength of the Anode Film

When the voltage across the film exceeds a certain critical value, sparking is observed to take place at the surface. This voltage, according to Schulze (28), is dependent on the valve metal as well as the nature and concentration of the electrolyte employed, but it is independent of the temperature and current density. The maximum voltage that can be maintained across the film depends on the nature and concentration (of free ions) of the electrolyte that is used for forming the film; it is apparently independent of the valve metal, the current density, and the temperature. For the film produced on aluminium in 0.1 N. solutions of various salts, Schulze (25) gives the following figures for the maximum voltage:—

Sodium sulphate	40 V.
Potassium permanganate	112
Ammonium chromate	122
Potassium cyanide	295
Ammonium bicarbonate	425
Sodium silicate	445
Ammonium phosphate (? dibasic)	460
Ammonium citrate	470
Borax	480
Citric acid	536

For tantalum in 0.05 N. solutions containing metal free anions (*e. g.* OH', $HCOO'$, C_3H_7COO', H_2PO_4', etc.) the maximum voltage averages about 480 V. (28): the cation, so long as it is not one of a heavy metal, has no influence. The presence of metal in the anions greatly influences the maximum voltage. In 0.05 N. solutions of metal containing anions, tantalum exhibits a maximum voltage of ca. 133 V. for chromium (*e. g.* Cr_2O_7''), ca. 84 V. for iron (*e. g.* $\frac{1}{3}$ $Fe(CN)_6'''$), and ca. 28 V. for platinum (*e. g.* $\frac{1}{2}$ $PtCl_4''$). In the range 0.5–0.05 N. an increase of about 1 per cent. in the dilution of the electrolyte produces an increase of about $\frac{1}{4}$ per cent. in the maximum voltage. At very low concentrations very high values (up to 1900 V.) for the maximum voltage may be reached.

W. R. Mott (16) gives the electric strength of the film formed on aluminium in phosphate solutions as 10^6 V./cm. C. I. Zimmerman (38) gives a slightly higher figure of $5-6\times10^6$ V./cm.

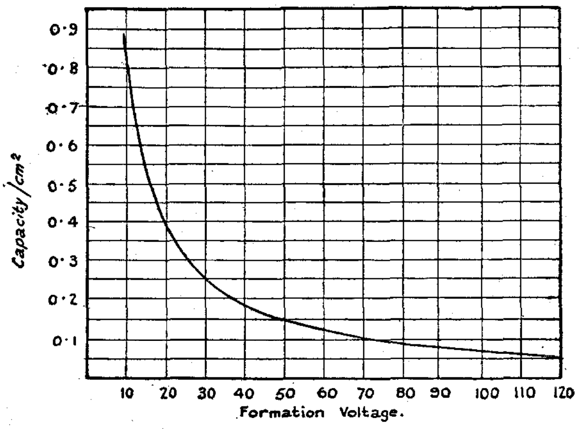


Figure 1—Variation of capacity/cm.^{2} *with formation voltage.* (*Bairsto & Mercer* (1).)

Electrostatic Capacity of the Active Layer

It has been mentioned above that the thickness of the active layer is determined by capacity measurements. This capacity varies approximately inversely with the potential applied to form the film, and amounts to about 0.7 m.f./cm.^{2} for formation at 10 V. D.C.(26), and 0.18 mF./cm.^{2} at 30 V. D.C. (29) for aluminium. Figure 1 shows a curve, which averages the results of several workers, giving the relationship between formation voltage and capacity/cm.^{2} for aluminium in aqueous electrolytes (1). The rate of growth of the active layer on an aluminium anode has been investigated by N. A. de Bruyne and R. W. W. Sanderson (2), who found that the reciprocal of the capacity increased to its final steady value approximately logarithmically with time. (See also (1) for a summary of other measurements.)

When the voltage applied to a cell is higher than that at which the film was originally formed, the film adjusts itself to correspond to the new voltage. When there is a large electrode surface in the cell, then this increased voltage may result in a heavy flow of current, which may cause overheating and damage to the cell if the film is not able to adjust itself with sufficient rapidity to the new condition. The insertion of a current limiting device in the circuit will prevent any such damage.

Under the reverse condition, where a cell is operated at a voltage lower than the forming voltage, a very slow adjustment to the new conditions takes place. An electrolytic condenser, with continued working, will gradually accommodate itself to the lower voltage; its capacity will slowly increase on account of electrolytic action on the film reducing its thickness. This rate of change is influenced by the temperature and the conductivity of the electrolyte, being more rapid for high temperatures and conductivities (see Figures 2 and 3). The variation of capacity with temperature appears to be characteristic of the electrolyte (1).

The capacity of an electrolytic condenser decreases with frequency, though many workers seem to have ignored this factor. The change which does occur is greater in condensers with electrolytes of high specific resistance and with films formed at low voltages. The capacity-frequency characteristic of a new aluminium electrolytic condenser and the same unit after a year's continuous service is shown in Figure 4. In this instance the fall in capacity is influenced also by the special shape of the anode plates, which are corrugated.

The Electrodes

(a) *The Anode.*

The purity of the metal employed as anode in electrolytic condensers and rectifiers has considerable influence on the efficiency, life, and corrosion of the cell.

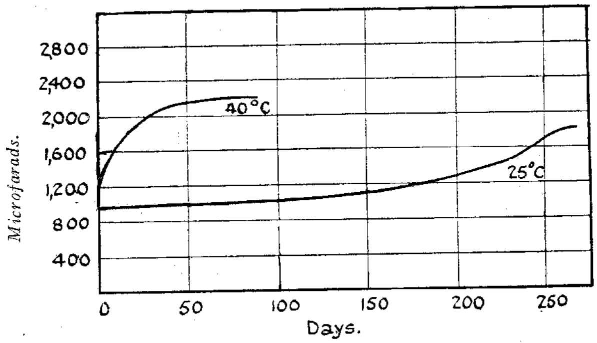


Figure 2—The capacity-time change of electrolytic condensers operated at half the formation voltage. Both with ammonium borate solution of same conductivity. Different temperatures. (Siegmund (29).)

For rectifying purposes, the copper content of aluminium is of importance. When this is less than 0.05 per cent., the current delivery and the life of the cell fall off rapidly, and when it is over 0.15 per cent. the life is reduced (8).

In electrolytic condensers the purity of the aluminium affects (29)

(*a*) the time of formation of the active layer,
(*b*) the D.C. leakage of the film,
(*c*) the number of cell failures due to corrosion.

As regards the time necessary for formation, this is more rapid with aluminium of 99.6 per cent. purity than of 99.1 per cent. purity. The D.C. leakage is also lower with the purer sample. For example, after formation at 60 V. for 24 hours,

99.1 per cent. pure aluminium passed ca. 3 microamps./cm.²

99.6 per cent. pure aluminium passed ca. 0.5 microamps./cm.²

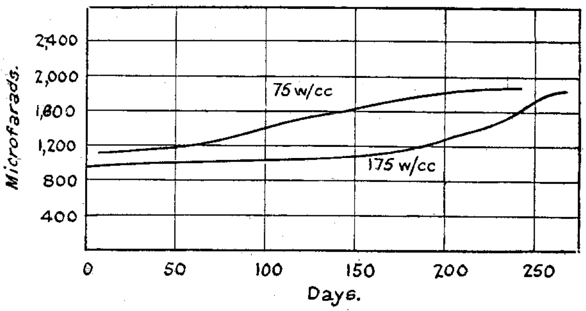
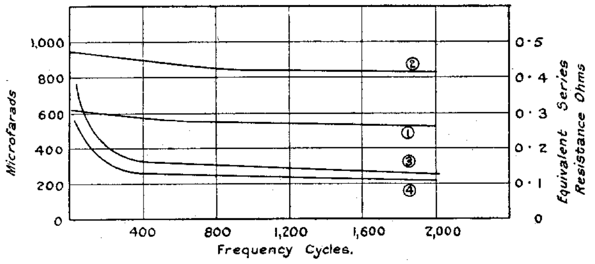


Figure 3—Capacity-time change of electrolytic condensers operated at half the formation voltage. Both at room temperature. Ammonium borate solution of different conductivities. (Siegmund (29).)

Although purer samples of aluminium appear to



(1) Capacity curve. Initial.
(2) Capacity curve after one year's continuous service.
(3) Resistance curve. Initial.
(4) Resistance curve after one year's continuous service

Figure 4—Capacity-frequency and resistance-frequency change of aluminium condenser formed at 100 V. and operated at 63 V. D.C. (Siegmund (29).)

be more readily corroded by the electrolyte, the best results in a solution of ammonium borate solution are obtained with a silicon content of 0.24 per cent.

The corrosion that occurs in electrolytic condensers makes itself apparent by pitting of the electrodes, the development of growths at the anode surface, and the deposition of sludge. There is no definite time at which corrosion starts; it may commence soon after a unit has been placed in service, or it may be delayed many months. Even when corrosion has taken place, condenser units will often continue to function for years. This seems to indicate that the corrosive influence may be eliminated after a time by chemical action, and that a protective film then forms over the affected area.

(b) *The Cathode.*

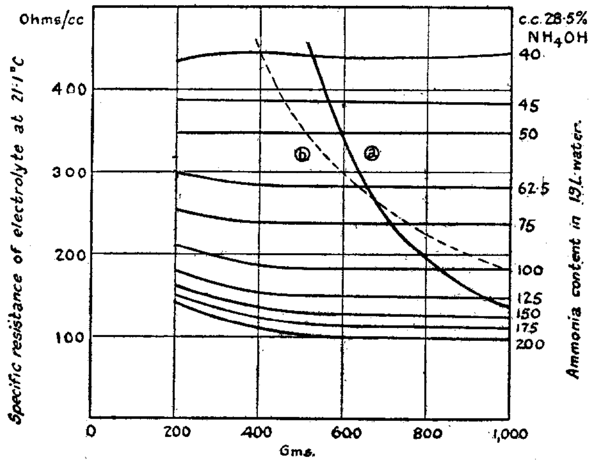
A formed aluminium electrode when made a cathode offers only a small resistance to current flow if the voltage is above a certain minimum value (the Mindestspannung of Schulze). This minimum potential is dependent upon the valve metal, the thickness of the active layer, as well as the nature and concentration of the electrolyte. It is independent of temperature.

In a condenser operating on a D.C. circuit the negative plate serves only to make contact with the electrolyte. Although not subjected to any intentional formation, there is a tendency for a film to form on the cathode (if it is a valve metal) during the periods that the condenser discharges. This may be overcome by using either an inert (non-valve) metal or an aluminium alloy containing sufficient amount of some substance, *e. g.* silicon, which hinders film formation. With an alloy containing less than 99 per cent. aluminium it is possible to have a C.D. of ca. 1 m.a. A.C./cm.^{2} of negative plate without sufficient film forming to affect the capacity of the cell (29).

The Electrolyte

The formation of the anode film takes place in acid or in alkaline solutions. The presence of acid ions in the electrolyte favours the formation of the insulating layer on an aluminium anode; alkaline ions favour its removal when the electrode is made cathode (21). The results obtained with different electrolytes are essentially the same, so long as a similar reaction occurs in each case at the electrode surface, although the electrical characteristics of the cell, such as its resistance and power factor, may be considerably modified. Generally speaking, the electrolytes that have shown themselves to be most suitable are solutions of ammonium or alkali salts of the weak acids such as borates, oxalates, tartrates, citrates, and salts of other organic acids. To assist the formation of aluminium plates C. Pollak (19, 20) adds about 3 per cent. of chromate to an alkaline or neutral electrolyte. Ammonium molybdate has been suggested (1) as a suitable electrolyte. However, one that is suitable for use in a condenser may be quite unsuitable for use in a rectifier.

An electrolyte that has shown itself to be particularly suitable for use in electrolytic condensers as used in telephone work is ammonium borate. The specific resistance of the solution for various proportions of boric acid and ammonia is shown in Figure 5 (29), which exhibits several interesting points. The intersection of the constant ratio boric acid-ammonia curve and the pH curve shows that the acidity of the ammonium borate solution decreases with the dilution: by adding sufficient water the solution may be made alkaline. The fact also emerges



(*a*) Neutral solution pH = 7.0. (Heavy curve.)
(*b*) Constant proportion of boric acid and ammonium. (Dotted curve.)

Figure 5—Specific resistance of ammonium borate solution. (Siegmund (29).)

that the specific resistance of the electrolyte is determined mainly by the ammonia content, and the acidity or alkalinity by the boric acid content. Control of the *p*H value of borate solutions can also be effected by adding glycerol (39) or certain sugars.

In choosing an electrolyte for a condenser regard should be had to the following points:—

(*a*) the specific resistance of the electrolyte and its influence on the electrical characteristics of the unit;

(*b*) the corrosive action of the solution on the metal electrodes;

(*c*) the life of the solution: that is to say, taking the case of aluminium, the rate at which it becomes saturated with aluminium hydroxide. During use, the small leakage current of the cell is accompanied by a corresponding solution of the metal.

In general, the lower the specific resistance of the solution the more rapidly the hydroxide forms (see Table VI). Although a high specific resistance is advantageous in reducing the rate of hydroxide formation, it increases the electrical impedance of the cell. The precipitation of hydroxide is more rapid at higher temperatures. Furthermore, when a formed anode is allowed to stand idle, deterioration of the film takes place, due to attack by the electrolyte.

TABLE VI.

Sp. resistance of ammonium borate solution.	Approx. life at 25° C. before aluminium hydroxide separates out.
75 ohms.	½–1 year.
150	1–3 years.
300	over 5 years.

Effect of Impurities in the Electrolyte

The formation of the anode film is highly sensitive to the presence of impurities in the electrolyte. Strong acids, heavy metals, and halogen, nitrate and chlorate ions destroy the unidirectional conductivity of an aluminium cell. The extremely small amounts of foreign substances that will interfere with the functioning of the cell are evident from the following results of Schulze (27). With an aluminium anode in 0.22 N. borax solution, sodium chloride in a concentration of 2.5×10^{-4} N. produces a noticeable retardation of forming. This amount is equivalent to ca. ½ per mil. of the borax, and is sufficient to produce a turbidity with silver nitrate solution. Any electrolyte giving this reaction should be rejected for the purpose of electrolytic condensers or rectifiers. Bromine and iodine ions act similarly. The action of sodium nitrate is not so great. A concentration of 0.002 N. (≡1 per cent. of the borax) retards the film formation. A slight alkalinity of the electrolyte is not objectionable, but a strong alkalinity destroys the valve action. Sodium hydroxide in a borax solution will react thus

$$2NaOH + Na_2B_4O_7 \rightarrow 2Na_2B_2O_4 + H_2O.$$

Seeing that the metaborate is not hydrolysed much more than the tetraborate, the sodium hydroxide will not become effective till its concentration is in excess of that of the borax.

The enormous increase in the leakage current of an aluminium anode when halogen ions are present is shown in Table VII.(1). The addition to a borax solution of a substance, *e. g.*, a sulphate, acetate, etc., which itself will allow film formation, but not to the same extent as borax, will have an unfavourable influence. Taylor and Inglis (34) have found that those salts (*e. g.*, KCl, KNO_3, etc.) that destroy the functioning of an aluminium cell are those that easily diffuse through an aluminium membrane. Other salts that do not diffuse through are without effect.

TABLE VII.

Electrolyte.	Gm. PO_4 ion. *a*.	Gm. Cl ion. *b*.	Ratio $\frac{a}{b} = \sigma$.	$\frac{\text{mA.}}{\text{cm.}^2}$	Ratio $\frac{i\sigma}{i_0}$.
130 c.c. NH_4NaHPO_4	0.59	—	—	0.0013	1
130 c.c. NH_4NaHPO_4					
+3½ c.c. KCl aq.	0·57	0·048	0·084	0·157	121
+4½ "	0·57	0·062	0·109	0·26	204
+5½ "	0·56	0·076	0·136	0·471	362
+6½ "	0·56	0·090	0·161	0·972	750
+7½ "	05·6	0·105	0·191	1·89	1450

Aluminium anode formed at 110 V. D.C.
Measurements made at 20 V. D.C.

Condenser Properties of Formed Electrodes

In considering the electrical properties of the electrolytic condenser, it is impossible not to make considerable reference to the exhaustive work of C. I. Zimmerman (37 & 83).

The active layer on a formed aluminium electrode constitutes an asymmetric dielectric, in that it can retain positive charges only on the side in contact with the metal. A single formed electrode immersed in electrolyte constitutes what is termed an asymmetric cell. Compared with an ordinary mica or plate condenser, the metal anode and the electrolyte correspond to the two conducting coatings, and the active layer or film to the dielectric. Two formed electrodes immersed in an electrolyte (two series-opposed asymmetric cells) are equivalent to two ordinary plate condensers in series, but the distribution of electrostatic charges internally is quite different from that which obtains in two series connected plate condensers, on account of the rectifying properties of the film. The potentials across the two films of an electrolytic condenser are in opposition to each other, whereas in the case of two series connected plate condensers the potentials across the individual dielectrics act in series. The condenser action of two series-opposed asymmetric cells results from the energy changes accompanying the variations in distribution of the constant charge held by the unit. Such an arrangement will not allow D.C. to pass; A.C. will, however, pass, producing a leading current in the circuit in which it is incorporated.

On connecting an electrolytic condenser consisting of two series-opposed asymmetric cells to an A.C. source of voltage, current flows until the impressed voltage on the cell terminals has reached its maximum. One electrode of the cell now has maximum voltage applied to it, and therefore has its maximum charge. As the potential decreases from its maximum value, the electrode which was positive starts to discharge into the circuit, and the charge which it held accumulates on the other electrode making this one now positive. For any subsequent variation of voltage the total coulomb charge remains constant (for a given maximum applied voltage), whereas in an ordinary plate condenser the charge varies with the applied voltage. The constant electrostatic charge existing in the cell sets up a uniform difference of potential between the electrolyte and any point outside the cell in the external circuit which is neutral with respect to the A.C. pressure. The electrolyte is always negative with respect to the neutral A.C. pressure reference point. The arithmetical sum of the potentials across the two films is constant, and equals the maximum voltage impressed on the condenser terminals. The algebraic sum of the instantaneous values equals the instantaneous value of the impressed voltage. The potential difference existing between the electrolyte and either electrode is the resultant of a uniform potential equal to one-half the maximum instantaneous value of the voltage impressed on the cell, and an A.C. voltage equal to one-half the effective value of the voltage impressed on the cell. This is a pulsating unidirectional pressure. Each film is subjected to an A.C. component equal to one-half the pressure impressed on the condenser; and each film is subjected to the maximum pressure impressed on the cell, instead of one-half as is the case with two ordinary plate condensers connected in series.

Energy Variation within the Cell

It has been mentioned above that when the charge on one electrode is at a maximum, the charge on the other is zero. The energy stored at the maximum voltage is therefore

$$W_1 = \tfrac{1}{2} Q E_{\text{max.}}$$

where Q = the charge in coulombs,
$E_{\text{max.}}$ = the maximum voltage.

At the moment the applied voltage becomes zero, each film holds one-half the charge at one-half the voltage; the stored energy then amounts to

$$W_2 = 2\left[\frac{1}{2} \times \frac{1}{2} \times \frac{E_{\text{max.}}}{2}\right]$$
$$= \tfrac{1}{4} Q E_{\text{max.}}$$

The energy variation is therefore $W_1 - W_2 = \tfrac{1}{4} Q E_{\text{max.}}$, or one-half the total energy stored in the condenser when maximum voltage is impressed on the terminals. Whereas an electrolytic condenser (two series-opposed asymmetric cells) stores and gives up only one-half of its total charge, an ordinary condenser stores and gives up its total charge. In the electrolytic condenser one film charges while the other discharges: in an ordinary condenser both electrodes charge and discharge together.

TABLE VIII.

Condenser.			Calculated capacity. mF.	Power factor.	Temp. °C.	Formation voltage. D.C.	Residual current at D.C. forming voltage. Amp.	Peak value of applied A.C.	Time of closed A.C. circuit. Mins.
Current. Amps.	Voltage. A.C.	Losses. Watts.							
1·26	27·4	2·25	146·3	0·065	19·7	40	0·003	ca. 33	120
1·35	59·2	4·0	72·6	0·050	18·0	80	0·0045	" 84	60
1·72	113·4	23·0	48·2	0·118	22·8	160	0·0037	" 159	60

When the two electrodes in an electrolytic condenser are not of the same electrostatic capacity, the charge stored in the condenser is independent of the capacity of the smaller electrode, and is determined solely by the maximum charge capable of being stored by the larger electrode. If one of the electrodes of the cell has negligible capacity, the unit no longer reacts on an A.C. circuit like an ordinary condenser, since it is able to receive a charge but unable to return it. In such a cell the potential difference between the smaller electrode and the electrolyte has a theoretical maximum value of twice the maximum pressure applied to the cell terminals.

Considerations of the electrical properties of polyphase electrolytic condensers have also been made by Zimmermann (38).

Electrical Losses of the Electrolytic Condenser

The losses associated with the electrolytic condenser are made up as follows:—

(*a*) A loss constant at all frequencies due to the inherent conductivity of the film, and which is equivalent to a high resistance in parallel with the capacity.

(*b*) Dielectric loss which, as in the case of the ordinary type of condenser, increases with frequency.

(*c*) I^2R losses due to the resistance of the electrolyte. Since the most suitable electrolytes for electrolytic condensers have a low conductivity, the losses due to this cause may be appreciable. The resistance of the electrolyte remains almost constant over a very wide range of frequencies.

(*d*) Losses due to electrolytic decomposition.

The composition of the electrolyte has considerable influence on the power factor of an electrolytic condenser when used on an A.C. circuit. For example, an electrolyte of the composition

30 gm. boric acid,
5 " ammonium borate,
1 L. water,

exhibits a P.F. of 40 per cent.; whilst the same solution with 4 gm. sodium hydroxide and ½ gm. sodium fluoride added exhibits a P.F. of 4·2 per cent. (13).

In Table VIII. are given some results obtained by Schulze (25) on an aluminium condenser working on A.C. The condenser consisted of ten plates of aluminium 9·7×16·5×0·1 cm. immersed in saturated ammonium borate ($(NH_4)HB_2O_4$); alternate plates were arranged to be anode and cathode. The P.F. increases as the value of the applied A.C. voltage increases (see Table IX.), and also with the time of closed circuit.

The condensers described by Siegmund (29), utilizing a solution of ammonium borate of specific resistance 225 ohms, have P.F.'s of the order of 9 per cent. measured at 60 cycles. In Table X. are given some values at different frequencies of the capacity and equivalent series

TABLE IX.

Calculated capacity. mF.	Voltage. A.C.	Current. Amp.	Losses. Watts.	Power factor.
43·9	102·8	1·42	8·6	0·059
43·9	82·8	1·14	5·0	0·053
43·8	73·6	1·01	3·5	0·047
43·6	59·2	0·81	1·7	0·041

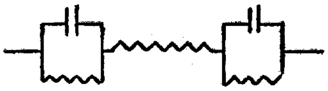
resistance for this type of condenser; Figure 6 shows the percentage variation in these values with temperature.

Various equivalent networks have been suggested as corresponding to a valve anode. N. A. de Bruyne and R. W. W. Sanderson ((2) *q. v.* for other references) assumed for experimental purposes that an electrolytic condenser having two similar plates was equivalent to the following network:—

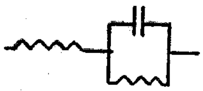
TABLE X.

	Frequency	Initial value.	Value after one year's service.
Capacity.	60~	640 mF.	930 mF.
	400	570	860
	1000	540	840
	2000	520	830
Equivalent series resistance.	60~	0·37 ω	0·27 ω
	400	0·15	0·125
	1000	0·14	0·12
	2000	0·12	0·11

Condenser formed at 100 V. D.C. and operated continuously for one year at 66 V. D.C. (Values have been read from a small scale graph.)



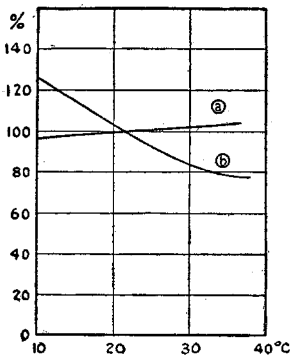
The capacities shunted by the resistances represent the leaky condensers at the electrodes, and the series resistance the resistance of the electrolyte. For two electrodes of equal area this network reduces to



In such a simple network, which lends itself to calculation, the values of the component parts were shown to be not independent of frequency. It would appear that there is no simple network which is capable of accurately representing the electrolytic condenser.

Application of the Valve Anode

The unidirectional current conducting characteristic of aluminium and tantalum anodes has found wide use for the rectification of A.C. to supply a source of D.C. for battery charging. The best results for rectification are obtained with high current density at the anode; low inductance and resistance of the external circuit; and low temperature. The capacity effect in the action of the valve lowers the E.M.F. of the rectified current (17). In consequence of the low conductivity of the electrolyte and the high resistance of the film, the I^2R losses are high. The use of a high current density for rectification purposes means that the I^2R heat is limited to a small space, and therefore there results a considerable rise in temperature, which must be kept down by using a large volume of electrolyte or by fitting special means for cooling the electrodes or electrolyte. As cathode in electrolytic rectifiers it is usual to use lead, iron, or carbon electrodes, and often the metal container itself.



(*a*) Capacity curve.
(*b*) Equivalent series resistance curve.

Figure 6—Percentage variation ∅, with temperature, of capacity and equivalent series resistance of 48 V. condenser at 1000∿. (Siegmund (28).)

The high resistance of the aluminium film to the passage of electric current has been utilised for preventing arcs on interrupting an inductive circuit (10). The B.D.V. of the electrolytic cell for this purpose should be greater than the normal working voltage of the circuit. On interrupting an inductive circuit the high voltage surge breaks down the film, which reforms when the circuit is operated again. The break-down characteristic of the aluminium anode is utilized in addition for the production of electrolytic lightning arrestors.

The high electrostatic capacity available at a valve anode has been utilized for the production of static condensers. The high losses associated with electrolytic condensers on A.C. circuits, however, precludes their use at high frequency voltages. Their usefulness is restricted to employment on low voltage circuits for protection against surges of steep wave front, and for use on D.C. circuits where it is desired to filter out an A.C. ripple.

In telephone work it has been the practice to build special generators which will give a smooth D.C. output that will not interfere with conversations when connected to telephone circuits. The ordinary commercial generators can be employed for charging the exchange battery associated with the telephone circuits, when used in conjunction with a filter circuit comprising chokes and condensers, which eliminates the ripple present in the current supplied by the power plant, and thereby cuts out hum from the the telephone circuits (36).

When an electrolytic condenser is used on a D.C. circuit it is sufficient to have a cell with one electrode of a valve metal such as aluminium, and one electrode of a non-valve metal. The condenser action is assured so long as the valve metal is kept positive. Such an arrangement on an A.C. circuit will act rather as a rectifier.

Aluminium condensers have been used for the production of high voltage D.C. (31). Several cells are connected in series and charged rapidly one after another by a rotating commutator; the whole set of cells is discharged in series.

The bulk and cost per microfarad of an electrolytic condenser are considerably less than that of an ordinary condenser operating at the same voltage. However, at higher voltages, where the efficiency is not so great, this economy is not so apparent, since the energy storing capacity of a condenser varies as the square of the impressed voltage.

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Type D-1 Single Channel Short Haul Carrier Telephone System

By J. W. SANBORN

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SINCE the birth of the telephone over fifty years ago, research and development have made many remarkable improvements not only in the speed of service and the quality of transmission, but in economies which make it possible to furnish this all-important means of communication at reasonable rates.

Outstanding among such developments is the more efficient use of the wire lines connecting two telephone centers.[2] Instead of obtaining one telephone circuit on one pair of wires it is now entirely practicable to obtain four telephone and two two-way telegraph circuits on one pair of wires, or nine telephone and four two-way telegraph circuits on a phantom group. This has been made possible largely by carrier telephone systems* which operate by the superposition of high frequency voice modulated currents on the wires.

One of these systems provides three high frequency telephone channels and has been used extensively not only in the United States[3],[6] but in Australia[4],[5] and to a lesser extent in other countries. There has also been developed an efficient single channel long haul carrier system.[7] These systems have proved capable of furnishing high grade circuits at annual costs less than required for additional wire circuits over the relatively long distances for which they were designed to operate. For short distances of less than 150–200 miles, however, they will not in general be economical inasmuch as the technique required for their adjustment and maintenance is relatively complicated and requires highly trained personnel.

There was a field, therefore, for a cheaper system which would be economical over shorter distances; this need was met by the development of a single channel short haul telephone carrier system, which will be briefly described.

Characteristics of D-1 System

The single channel short haul system[1] is called the Type D-1. It is somewhat similar to the three-channel type C system but is much simpler in operation. It has been designed particularly to provide an additional circuit over distances as low as 50 to 75 miles at annual charges less than those of additional copper circuits. To accomplish this necessitated among other things, a design of system in which the maintenance cost would be low. The new system employs equipment which requires very little adjustment or other attention and operates with hardly more attention than an ordinary telephone repeater. When necessary, the equipment can be used in stations which do not have regular maintenance but which are observed by a trained maintenance man once or twice a day. The circuits have a high degree of stability, and the adjustments of gain, battery voltage, and frequency necessary on other carrier systems are not required, since these factors remain sensibly constant after the circuit is initially lined up for operation.

The transmission characteristics of the D-1 system are such that where only one system is installed on a pole lineman overall equivalent of 3.5 db† is possible if the attenuation of the line is not over 20 db at the highest carrier frequency. On account of crosstalk where several systems are used on the same pole lead the above minimum overall equivalent cannot be satisfactorily obtained if the line attenuation is more than about 14 db. These values are based on a maximum gain at the transmitting end of 6.5 db and a maximum receiving gain in the first case of 10 db and again in the second case of 4 db.

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[2] For numerical references, see *Bibliography.*

* J. S. Jammer, "Carrier Telephone Systems and Their World Wide Application," *Electrical Communication,* Vol. VII, No. 4, April, 1929.

† G. H. Gray, "The Unit of Transmission and the Transmission Reference System," *Electrical Communication,* Vol. VIII, No. 1, July, 1929.

In the type D-1 system no intermediate amplifier is used. The apparatus consists of two terminal sets which are shown schematically in Figure 1. The equipment at either terminal consists of the line filter, transmitting and receiving band filters, the channel unit and the signal unit. The carrier frequency for transmission is 10.3 kilocycles in one direction, and 6.87 kilocycles in the other direction. In both cases the carrier is suppressed and only the lower side band is transmitted.

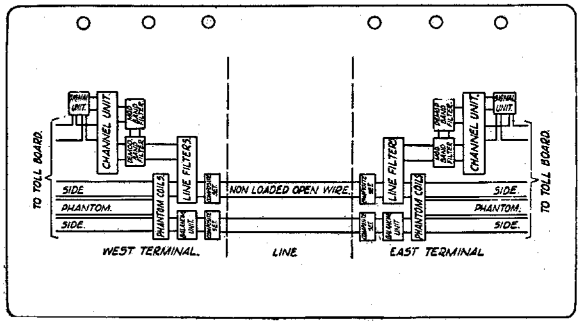

Figure 1—Schematic of Type D-1 Carrier System Applied to One Pair of a Phantom Group.

In applying the D-1 system it should be borne in mind that the carrier frequencies are nearly the same as those of the two lowest channels of one of the three-channel systems known as the C-N-3 or "normal" type. For this reason, therefore, a D-1 system cannot ordinarily be operated on the same line. Since the frequencies of the C-S-3 or so-called "staggered" type do not overlap those of the D-1 system to as great an extent (Figure 2), a limited number of the "staggered" type can be used on the same pole line with several type D-1 systems, as will be explained more fully under the discussion of transpositions.

The necessary power supply for the operation of the single channel carrier telephone system consists of a 24 volt filament supply, a 130 volt plate battery supply, and 20 cycle current for ringing.

No differentiation is made in operating practices between carrier and other circuits. Both appear on the toll switchboard and are handled by the operator exactly alike.

Because of its simplicity the type D-1 carrier has proved very useful under emergency conditions. In one case where the main pole line was put out of service by a storm, a carrier terminal was moved from one exchange to another and was put in service over a second unharmed toll line through the storm area in a time of only thirty-two hours. In another case of serious flood, five carrier systems were installed in a few days' time and were used for emergency service over a secondary route until the main toll lines in the stricken area could be rebuilt.

Equipment

The office equipment for the type D-1 carrier system has been so designed that one terminal may be mounted on a 7 ft. floor rack or two complete terminals may be mounted on an 11 ft. 6 in. relay rack bay. The floor rack mounted unit is constructed of channel iron and the equipment is assembled and wired before shipment (Figure 3). Where the bay type of layout is used, either I-beam or channel iron construction is satisfactory depending upon local office conditions. In this case the equipment is shipped as individual panels and is assembled and wired on the rack locally.

As indicated in Figure 1, the equipment comprises a channel unit with associated filters and signal unit. It is cross-connected to the toll line on the drop side of the telegraph composite set.

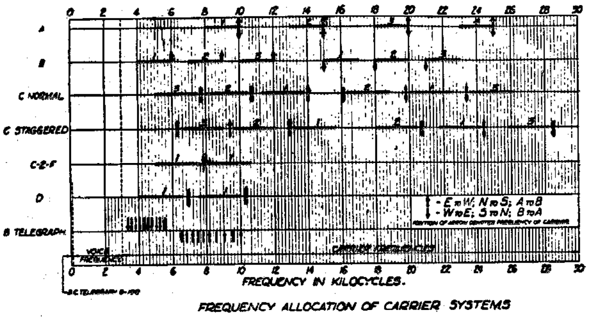

Figure 2—Frequency Allocation of Carrier Systems.

In Figure 4 is shown a simplified schematic diagram of the channel unit, essential parts of which are the hybrid coil, modulator low pass filter, modulator and demodulator, gain adjusting pads and some parts of the transmitting system. The channel units for the two terminals of the system are fundamentally the same, differing only in the electrical constants of certain of the coils and condensers, since one terminal transmits the low frequency band and receives the high frequency band, while the other terminal transmits the high frequency band and receives the low frequency band.

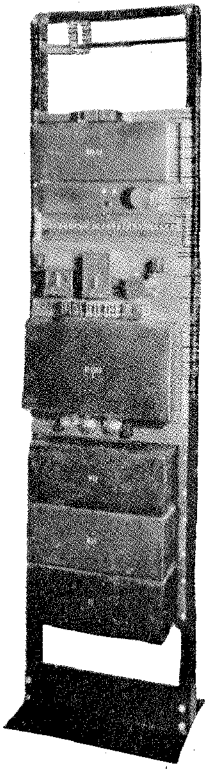

Figure 3—Floor Rack Mounted Terminal Unit.

The channel unit circuits differ from those used on other carrier systems in two important ways:

(1) They combine the functions of both carrier supply and modulation in one pair of tubes.

(2) They do not require batteries in the grid circuit, since modulation is accomplished by the use of resistances and condensers in the grid circuit.

The self-oscillating modulator circuits result in decided economy in use of tubes and power. Their function is performed by the use of tuned coupling between the common input and output of the two tubes, an arrangement which produces oscillations around the common circuit and supplies carrier frequency voltage to the grids. The amplitude of the carrier wave is predetermined by the electrical constants of the circuit and does not require any adjustment. The carrier frequency is suppressed in the output circuit by the connection of the output transformer and hence is not transmitted to the line. At the receiving end the carrier frequency is generated for demodulation by a similar circuit. The oscillating circuits are very stable, and when once properly adjusted they maintain the proper frequency without any further adjustment or attention. Small steps are arranged in the frequency adjustment so that the frequency at the receiving end may be set within one cycle of the value at the transmitting end. The nominal frequencies of the carrier waves are 10,300 cycles at one terminal and 6,867 at the other terminal.

The gains at the two terminals may be adjusted by the two pads which appear at the right-hand side of Figure 4. The pad in the modulator output circuit has a range of 11 db in 1 db steps for adjusting the transmitting level. The pad at the receiving end precedes the input transformer and has a range of 31 db in steps of 1 db. Once these have been adjusted they should not require changing unless the circuit layout is changed. The overall stability of the system is such that the toll circuit equivalent will stay without adjustment within the commonly accepted limits of plus or minus 2 db. Most of this variation will be due to weather changes on the line, and not to the carrier equipment.

The hybrid coil performs a double function, serving also as an input transformer for the modulator circuit. The side of the coil to which the balancing network is connected (Figure 4) is brought out to terminals so that a precision network may be used instead of the compromise condenser and resistance network. The precision network will usually be required when the system is extended to another toll circuit, but the compromise network is, in general, satisfactory if the toll circuit terminates at the carrier terminal.

The modulator and demodulator circuits are separated by two band filters, located between the line filters and the channel unit. All coils are wound on non-metallic cores and the filter units are sealed in copper boxes for protection and shielding. Each filter passes the lower side band of one of the carrier frequencies and effectively suppresses all other frequencies.

A special line filter set has been designed for use with type D-1 systems, the low pass section passing frequencies of the voice channel up to 2,800 cycles and the high pass section passing frequencies above 4,000 cycles. This filter set is simpler and cheaper than those used with the three-channel systems and is designed to meet the requirements of this system only. If these filters are introduced in one side circuit only of a phantom group, they, of course, will tend to unbalance the phantom circuit. To prevent this, phantom balance coils have been designed for use in the other side circuit as shown in Figure 1. If type D-1 systems are used on both side circuits of a phantom group, the filters will balance each other and the balance coils are unnecessary.

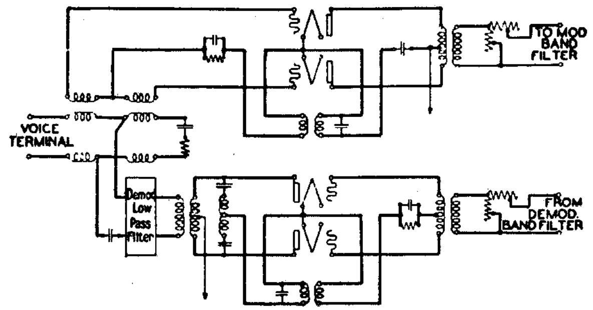

Figure 4—Simplified Schematic of Channel Unit.

In order to preserve the necessary two-wire repeater balance on voice frequency circuits when these filter and balancing units are used, a second filter or balancing unit must be inserted in the repeater network. With this in mind, a unit is produced consisting of two of these line filter units which have been specially selected at the factory to balance to 24 db or better and which are mechanically joined together.

The type D-1 system is also unique in that its signaling current is obtained directly by modifying the modulator circuit give to a current at the 1000 cycle point of the side band. This is accomplished by operation of a relay which unbalances the modulator circuit by opening the plate circuit of one of the tubes and which at the same time introduces a condenser into the oscillating circuit so that the frequency is shifted to a point 1000 cycles below the normal carrier frequency, that is, to the 1000 cycle point of the lower side band. This current is interrupted by a relay which operates from local 20 cycle ringing current. At the receiving end the interrupted high frequency current comes in through the line and band filters to the demodulator, where it combines with local carrier current to give an interrupted current at 1000 cycle frequency. This 1000 cycle current in turn is amplified and passed through relays which finally cause local 20 cycle ringing current to operate the switchboard signal. A small testing unit is required for adjusting the relay in the signal unit. This is mounted with the first terminal installed in each office, and serves for any other terminals that may be added.

If the installation is in a station where repeaters are used, the 24 volt and 130 volt batteries used for the repeaters can, of course, be used also for the carrier system. The current drain from the filament and plate batteries will be about 1 ampere and 20 milliamperes, respectively, for each terminal in use. However, it may be desired to install carrier systems between offices where there are no repeaters, and for such use small 24 volt and 130 volt power plants capable of supplying 2 amperes and 130 milliamperes respectively have been designed.

From the preceding it will be apparent that the apparatus requires practically no adjustments other than those which are made in the carrier frequencies and in the pads when the circuit is initially lined up.

Outside Plant Considerations

In applying the type D-1 telephone system to toll lines, there are several points in connection with the outside plant which have to be taken into account, such as the question of carrier transpositions, loading of entrance or intermediate cable, and in some cases, filters for transferring the circuit from one line to another.

Transpositions

A single type D-1 carrier system can generally be operated over an existing open wire circuit which is transposed according to any of the standard methods, with no additional transpositions. This may also be true for several systems, depending in each particular case upon the transposition scheme in use, the number of systems involved, the separation actually obtainable between systems and the existence of any irregularities in the line attenuation characteristics. The feasibility of using several systems without carrier transpositions is best determined by carrier crosstalk and attenuation tests upon the circuits involved.

Where it is found that transpositions are needed, the probabilities are that by superposing extra transpositions on the present well-known Standard or Exposed Line systems of transpositions in all side circuits to be equipped with carrier systems, it will be possible to use the type D-1 system on the side circuits of all end phantom groups on the first four crossarms. It will probably be practicable also to employ transpositions which will permit the use of two "staggered" (type C-S-3) carrier systems on the top crossarm and type D-1 systems on the sides of end phantom groups on the three lower arms. As has been pointed out previously, it is in general not possible to use the "normal" (type C-N-3) system or any other multi-channel carrier system except the "staggered" type on the same pole line with type D-1 systems without sacrificing at least the lower channel on the multi-channel systems.

Due to the large output current of a carrier telegraph circuit, its crosstalk into a type D-1 carrier telephone system is, in general, about 15 db higher than that of one telephone system into another. It is evident, therefore, that the use of carrier telegraph and type D-1 carrier telephone on the same pole line is necessarily limited, and is feasible only where the two are well separated. Conditions are even worse if a telegraph repeater or terminal comes within the carrier telephone section.

Except for the limitations above noted, the type D-1 system does not impede the use of other facilities on the pole line. DC telegraph circuits and ordinary phantom circuits can be used with the type D-1 system, provided, that proper attention is paid to balancing the sides of the phantom groups, as previously discussed.

Cable Loading

The single channel carrier system was designed for use on open wire lines, and cable runs should be avoided where possible. In case entrance or intermediate cable is necessary it must be loaded, unless it is very short, not only to lower the attenuation, but, what is even more important, to prevent crosstalk due to reflected currents from the cable junctions in cases where there is more than one carrier system on the line. A special type of loading, using 15 millihenry coils at 3000 ft. spacing in the side circuits and 16 millihenry in the phantom, has been designed for this use. This loading gives a nominal impedance of 640 ohms and a cutoff frequency of 13 kilocycles. It is designed to match the impedance of No. 13 NBS gauge (.104 in. diam.) non-pole pair, non-loaded open wire circuits. Due to the greater spacing of the coils it is cheaper than the system of carrier loading which is used in connection with the three-channel system, but its comparatively low cutoff frequency limits its use to circuits involving only the single channel carrier. Loading coil cases are available to hold the coils necessary for any number of phantom groups up to five.

Transfer Arrangements

It may be desired to transfer the carrier channel from one circuit to another at an office where the physical circuit is tapped or terminated, or at some intermediate point. This may be accomplished by using proper filter units. If the circuits need to be insulated from each other, a carrier repeating coil may be inserted between the two transfer filters. Due care must also be taken to preserve phantom circuit and repeater balances at transfer points. It is not expected, however, that the necessity for transferring the carrier channel will arise very often, since the range over which the carrier system is designed to operate is comparatively short.

Conclusion

The type D-1 single channel short haul carrier telephone system is already in extensive use. Since it is a comparatively inexpensive system to install and a simple one to maintain, these advantages together with the low annual charge should open a wide field for its application where there is a need for additional short haul circuits on an existing openwire lead at a minimum of expense, and where ease of operation comparable with that of an ordinary telephone repeater is required.

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Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1928

	Number of Telephones			Per Cent of Total World	Telephones per 100 Population	Increase in Number of Telephones During 1927
	Government Systems	Private Companies	Total			
NORTH AMERICA:						
United States	—	18,522,767	18,522,767	59.77%	15.8	776,599
Canada	226,673	1,033,314	1,259,987	4.07%	13.2	58,979
Central America	9,682	12,829	22,511	.07%	0.3	2,228
Mexico	1,427	63,489	64,916	.21%	0.4	7,353
West Indies:						
Cuba	491	68,337	68,828	.22%	1.9	3,612
Porto Rico	*820*	*12,402*	*13,222*	*.04%*	*0.9*	*—152*
Other W. I. Places*	7,790	10,583	18,373	.06%	0.3	213
Other No. Am. Places*	100	8,900	9,000	.03%	2.6	500
Total	246,983	19,732,621	19,979,604	64.47%	12.5	849,332
SOUTH AMERICA:						
Argentina	—	232,041	232,041	.75%	2.2	27,578
Bolivia	—	2,612	2,612	.01%	0.1	788
Brazil	636	107,553	108,189	.35%	0.3	2,980
Chile	—	38,573	38,573	.13%	0.7	1,713
Colombia	50	21,060	21,110	.07%	0.3	2,235
Ecuador	1,442	2,965	4,407	.01%	0.2	—111
Paraguay	183	230	413	.001%	0.03	—
Peru	—	13,695	13,695	.04%	0.2	466
Uruguay	—	26,934	26,934	.09%	1.5	19
Venezuela	*641*	*12,457*	*13,098*	*.04%*	*0.4*	*366*
Other So. Am. Places	2,738	—	2,738	.01%	0.6	30
Total	5,690	458,120	463,810	1.50%	0.6	36,064
EUROPE:						
Austria	165,231	—	165,231	.53%	2.4	6,802
Belgium	196,691	—	196,691	.63%	2.5	20,119
Bulgaria	14,358	—	14,358	.05%	0.3	4,348
Czechoslovakia	122,277	11,846	134,123	.43%	0.9	5,167
Denmark	13,040#	311,192	324,232	1.05%	9.3	3,123
Finland	973	108,000	108,973	.35%	3.0	20,417
France	883,406	—	883,406	2.85%	2.2	60,536
Germany	2,814,996	—	2,814,996	9.08%	4.4	126,501
Great Britain and No. Ireland	1,633,802	—	1,633,802	5.27%	3.6	122,217
Greece	8,000	—	8,000	.03%	0.1	1,672
Hungary*	120,000	—	120,000	.39%	1.4	5,000
Irish Free State (March 31, 1928)	25,317	—	25,317	.08%	0.8	1,487
Italy (June 30, 1928)	—	292,867	292,867	.95%	0.7	20,434
Jugo-Slavia	31,393	—	31,393	.10%	0.2	3,015
Latvia (March 31, 1928)	29,165	—	29,165	.09%	1.2	4,973
Netherlands	238,602	—	238,602	.77%	3.1	13,254
Norway	104,480†	75,004	179,484	.58%	6.4	3,984
Poland	93,590	63,835	157,425	.51%	0.5	25,474
Portugal	*3,000**	*21,127*	24,127	.08%	0.4	1,677
Roumania	56,024	—	56,024	.18%	0.3	2,750
Russia¶	260,000	—	260,000	.84%	0.2	20,000
Spain	—	141,214	141,214	.46%	0.6	9,695
Sweden	465,132	1,655	466,787	1.51%	7.7	16,141
Switzerland	223,597	—	223,597	.72%	5.6	13,111
Other Places in Europe*	75,134	18,459	93,593	.30%	1.1	4,000
Total	7,578,208	1,045,199	8,623,407	27.83%	1.6	515,897
ASIA:						
British India (March 31, 1928)	19,955	31,883	51,838	.17%	0.02	5,940
China*	80,000	50,000	130,000	.42%	0.03	5,000
Japan (March 31, 1928)	750,561	—	750,561	2.42%	1.2	102,470
Other Places in Asia*	95,000	15,000	110,000	.35%	0.1	1,000
Total	*945,516*	*96,883*	*1,042,399*	*3.36%*	*0.1*	*114,410*
AFRICA:						
Egypt	40,102	—	40,102	.13%	0.2	2,397
Union of South Africa*	97,155	—	97,155	.31%	1.3	6,500
Other Places in Africa*	65,000	1,100	66,100	.21%	0.1	6,000
Total	202,257	1,100	203,357	.65%	0.1	14,897
OCEANIA:						
Australia (June 30, 1927)	442,362	—	442,362	1.43%	7.2	38,746
Dutch East Indies	42,068	3,930	45,998	.15%	0.1	3,099
Hawaii	—	21,441	21,441	.07%	7.0	1,793
New Zealand (March 31, 1928)	144,552	—	144,552	.47%	10.0	7,245
Philippine Islands	5,135	14,739	19,874	.06%	0.2	2,060
Other Places in Oceania*	2,900	600	3,500	.01%	0.2	200
Total	637,017	40,710	677,727	2.19%	0.9	53,143
TOTAL WORLD	9,615,671	21,374,633	30,990,304	100.00%	1.6	1,583,743

* Partly estimated. # March 31, 1928. † June 30, 1927. ¶ U. S. S. R., including Siberia and Associated Republics; partly estimated.

Telephone and Telegraph Wire of the World, by Countries

January 1, 1928

	Service Operated by (See Note)	Miles of Telephone Wire			Miles of Telegraph Wire (See Note)		
		Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	63,836,182	60.47%	54.4	2,152,230	31.94%	1.8
Canada	P.G.	3,591,035	3.40%	37.5	323,539	4.80%	3.4
Central America	P.G.	44,656	.04%	0.7	21,288	.31%	0.3
Mexico	P.G.	304,016	.29%	2.0	85,371	1.27%	0.6
West Indies:							
Cuba	P.G.	238,765	.22%	6.7	14,022	.21%	0.4
Porto Rico	P.G.	28,407	.03%	1.9	1,098	.02%	0.1
Other W. I. Places*	P.G.	38,362	.04%	0.6	4,381	.06%	0.1
Other No. Am. Places*	P.G.	18,000	.02%	5.2	10,000	.15%	2.9
Total		68,099,423	64.51%	42.6	2,611,929	38.76%	1.6
SOUTH AMERICA:							
Argentina	P.	723,393	.68%	6.8	207,817	3.08%	2.0
Bolivia	P.	2,679	.003%	0.1	7,150#	.11%	0.2
Brazil	P.G.	283,442	.27%	0.7	104,586	1.55%	0.3
Chile	P.	58,504	.05%	1.3	40,529	.60%	0.9
Colombia	P.	34,680	.03%	0.4	20,066	.30%	0.3
Ecuador	P.G.	5,099	.01%	0.2	4,629	.07%	0.2
Paraguay	P.G.	138	—	0.01	2,223	.03%	0.2
Peru	P.	39,919	.04%	0.6	12,023	.18%	0.2
Uruguay	P.	41,641	.04%	2.4	6,465	.10%	0.4
Venezuela	P.G.	34,734	.03%	1.1	6,353	.09%	0.2
Other So. Am. Places	G.	4,755	.01%	1.0	786	.01%	0.2
Total		1,228,984	1.16%	1.6	412,627	6.12%	0.5
EUROPE:							
Austria	G.	519,728	.49%	7.6	48,468	.72%	0.7
Belgium	G.	861,457	.82%	10.9	27,140	.40%	0.3
Bulgaria	G.	43,961	.04%	0.8	7,821	.12%	0.1
Czechoslovakia	P.G.	304,000	.29%	2.1	44,136	.65%	0.3
Denmark	P.G.	852,568	.81%	24.4	8,947	.13%	0.3
Finland	P.G.	175,693	.17%	4.9	8,190	.12%	0.2
France	G.	2,468,863	2.34%	6.0	442,000	6.56%	1.1
Germany	G.	10,608,000	10.06%	16.7	417,000	6.19%	0.7
Great Britain and No. Ireland†	G.	7,278,000	6.89%	16.0	363,000	5.39%	0.8
Greece	G.	13,465	.01%	0.2	30,895	.46%	0.5
Hungary*	G.	268,000	.25%	3.1	52,000	.77%	0.6
Irish Free State (March 31, 1928)	G.	79,418	.08%	2.6	23,473	.35%	0.8
Italy (June 30, 1928)	P.G.	700,000*	.66%	1.7	216,817	3.22%	0.5
Jugo-Slavia	G.	98,760	.09%	0.7	56,506	.84%	0.4
Latvia (March 31, 1928)*	G.	138,000	.13%	6.9	5,500	.08%	0.3
Netherlands*	G.	496,000	.47%	6.5	30,000	.44%	0.4
Norway (June 30, 1927)	P.G.	511,941	.49%	18.3	24,900	.37%	0.9
Poland	P.G.	513,733	.49%	1.7	49,135	.73%	0.2
Portugal*	P.G.	78,880	.07%	1.3	20,000	.30%	0.3
Roumania	G.	174,573	.17%	0.9	45,093	.67%	0.2
Russia¶	G.	1,200,000	1.14%	0.8	415,000	6.16%	0.3
Spain	P.	170,000*	.16%	0.8	79,903	1.19%	0.4
Sweden	G.	1,060,264	1.00%	17.4	55,401	.82%	0.9
Switzerland	G.	642,266	.61%	16.1	21,915	.32%	0.6
Other Places in Europe*	P.G.	273,000	.26%	3.2	25,500	.38%	0.3
Total		29,530,570	27.99%	5.6	2,518,740	37.38%	0.5
ASIA:							
British India (March 31, 1928)	P.G.	337,989	.32%	0.1	399,515	5.93%	0.1
China*	P.G.	210,000	.20%	0.05	85,000	1.26%	0.02
Japan (March 31, 1928)	G.	2,515,421	2.38%	4.1	193,302	2.87%	0.3
Other Places in Asia*	P.G.	262,000	.25%	0.2	115,000	1.71%	0.1
Total		3,325,410	3.15%	0.4	792,817	11.77%	0.1
AFRICA:							
Egypt	G.	166,024	.16%	0.8	33,500	.50%	0.2
Union of South Africa*	G.	365,000	.34%	4.7	50,000	.74%	0.6
Other Places in Africa*	P.G.	125,000	.12%	0.1	130,000	1.93%	0.1
Total		656,024	.62%	0.5	213,500	3.17%	0.2
OCEANIA:							
Australia (June 30, 1927)	G.	1,910,981	1.81%	31.0	130,917	1.94%	2.1
Dutch East Indies	P.G.	199,152	.19%	0.4	20,611	.31%	0.04
Hawaii	P.	63,557	.06%	20.7	0	.00%	0.0
New Zealand (March 31, 1928)	G.	499,639	.47%	34.5	26,363	.39%	1.8
Philippine Islands	P.G.	38,398	.03%	0.3	9,783	.14%	0.1
Other Places in Oceania*	P.G.	6,000	.01%	0.4	1,400	.02%	0.1
Total		2,717,727	2.57%	3.7	189,074	2.80%	0.3
TOTAL WORLD		105,558,138	100.00%	5.5	6,738,687	100.00%	0.4

Note: Telegraph Service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and the Government.

* Partly estimated. † March 31, 1928. # January 1, 1927. ¶ U. S. S. R., including Siberia and Associated Republics; partly estimated.

Telephone Development of Large Cities

January 1, 1928

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINA:			
Buenos Aires	2,031,000	129,503	6.4
AUSTRALIA:			
Adelaide	328,000	29,517	9.0
Brisbane	295,000	21,701	7.4
Melbourne	975,000	85,884	8.8
Sydney	1,101,000	103,254	9.4
AUSTRIA:			
Vienna	1,957,000	105,420	5.4
BELGIUM:			
Antwerp	505,000	28,131	5.6
Brussels	913,000	67,505	7.4
Ghent	260,000	8,067	3.1
Liege	415,000	13,521	3.3
CANADA:			
Montreal	880,000	161,380	18.3
Ottawa	178,000	35,252	19.8
Toronto	657,000	173,264	26.4
CHINA:			
Canton	943,000	2,475	0.3
Shanghai	1,600,000	27,217	1.7
Tientsin	846,000	9,085	1.1
Peiping (Peking)	1,350,000	29,857	2.2
CUBA:			
Havana	581,000	46,998	8.1
CZECHOSLOVAKIA:			
Prague	718,000	32,465	4.5
DANZIG, FREE CITY OF	390,000	17,508	4.5
DENMARK:			
Copenhagen	775,000	126,849	16.4
FINLAND:			
Helsingfors	218,000	25,674	11.8
FRANCE:			
Bordeaux	258,000	13,976	5.4
Lille	204,000	12,212	6.0
Lyons	576,000	21,487	3.7
Marseilles	659,000	21,128	3.2
Paris	2,900,000	314,541	10.8
GERMANY:			
Berlin	4,105,000	448,030	10.9
Bremen	300,000	29,610	9.9
Breslau	569,000	39,619	7.0
Chemnitz	338,000	25,121	7.4
Cologne	714,000	61,682	8.6
Dresden	631,000	55,431	8.8
Düsseldorf	441,000	40,496	9.2
Essen	481,000	24,846	5.2
Frankfort-on-Main	477,000	54,416	11.4
Hamburg-Altona	1,290,000	157,710	12.2
Hanover	431,000	33,262	7.7
Leipzig	693,000	62,309	9.0
Magdeburg	300,000	20,139	6.7
Munich	707,000	66,396	9.4
Nuremberg	475,000	32,582	6.9
Stuttgart	348,000	38,839	11.2
GREAT BRITAIN AND NORTHERN IRELAND: (March 31, 1928)			
Belfast	421,000	13,623	3.2
Birmingham	1,085,000	43,699	4.0
Blackburn	129,000	3,896	3.0
Bolton	182,000	5,102	2.8
Bradford	319,000	16,565	5.2
Bristol	396,000	15,760	4.0
Edinburgh	426,000	24,153	5.7
Glasgow	1,136,000	51,026	4.5
Hull	347,000	15,497	4.5
Leeds	489,000	18,955	3.9
Liverpool	1,133,000	51,591	4.6
London	7,520.000	578,322	7.7
Manchester	1,070,000	55,255	5.2
Newcastle	465,000	16,947	3.6
Nottingham	297,000	13,311	4.5
Plymouth	213,000	5,701	2.7
Sheffield	498,000	16,525	3.3

Telephone Development of Large Cities—(Concluded)

January 1, 1928

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
HUNGARY (January 1, 1927):			
Budapest	985,000	49,120	5.0
Szegedin	126,000	2,359	1.9
IRISH FREE STATE (March 31, 1928):			
Dublin	400,000	14,032	3.5
ITALY (January 1, 1929):			
Milan	831,000	56,315	6.8
Rome	771,000	32,528	4.2
JAPAN (March 31, 1928):			
Kobe	667,000	25,581	3.8
Kyoto	736,000	31,166	4.2
Nagoya	870,000	26,007	3.0
Osaka	2,334,000	90,744	3.9
Tokio	2,218,000	129,548	5.8
Yokohama	537,000	13,398	2.5
LATVIA (March 31, 1927):			
Riga	343,000	11,215	3.3
NETHERLANDS:			
Amsterdam	735,000	41,057	5.6
The Hague	445,000	33,265	7.5
Rotterdam	572,000	35,643	6.2
NEW ZEALAND (March 31, 1928):			
Auckland	204,000	17,460	8.6
Christchurch	123,000	11,188	9.1
Wellington	128,000	17,167	13.4
NORWAY (June 30, 1927):			
Oslo	252,000	42,609	16.9
PHILIPPINE ISLANDS:			
Manila	338,000	13,586	4.0
POLAND:			
Warsaw	1,050,000	41,163	3.9
ROUMANIA:			
Bucharest	808,000	14,357	1.8
RUSSIA (March 31, 1928):			
Leningrad	1,630,000	53,090	3.3
Moscow	2,040,000	65,350	3.2
Odessa	415,000	4,167	1.0
SPAIN:			
Barcelona	761,000	21,267	2.8
Madrid	808,000	23,936	3.0
Seville	216,000	1,926	0.9
Valencia	268,000	4,259	1.6
SWEDEN:			
Göteborg	233,000	31,483	13.5
Malmö	117,000	15,875	13.6
Stockholm	398,000	114,923	28.9
SWITZERLAND:			
Basel	143,000	16,476	11.5
Berne	110,000	13,231	12.0
Geneva	127,000	17,060	13.4
Zürich	218,000	29,077	13.3
UNITED STATES*:			
New York	6,124,000	1,599,915	26.1
Chicago	3,185,000	903,460	28.4
Los Angeles	1,270,000	333,971	26.3
Total of the 8 cities with over 1,000,000 population	18,170,000	4,357,886	24.0
San Francisco	730,000	239,155	32.8
Cincinnati	672,000	154,021	22.9
Milwaukee	655,000	137,303	21.0
Washington	512,000	147,347	28.8
Total of the 11 cities with 500,000-1,000,000 population	7,363,000	1,495,708	20.3
Minneapolis	482,000	122,279	25.4
Portland, Ore.	366,000	92,862	25.4
Seattle	399,000	109,645	27.5
Omaha	231,000	62,179	26.9
Total of the 30 cities with 200,000-500,000 population	8,831,000	1,788,069	20.2
Total of the 49 cities with over 200,000 population	34,364,000	7,641,663	22.2

* There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups and the development of certain representative cities within each of such groups.

Telephone Development of Large and Small Communities
January 1, 1928

Country	Service Operated by (See Note)	Number of Telephones		Telephones per 100 Population	
		In Communities of 50,000 Population and over	In Communities of less than 50,000 Population	In Communities of 50,000 Population and Over	In Communities of less than 50,000 Population
Australia (June 30, 1927)*	G.	249,481	192,881	8.6	5.9
Belgium	G.	143,377	53,314	4.5	1.1
Canada	P.G.	608,300	651,687	22.0	9.6
Czechoslovakia	P.G.	55,637	78,486	4.0	0.6
Denmark	P.G.	144,149	180,083	15.9	6.9
France	G.	522,962	360,444	6.0	1.1
Germany	G.	1,722,644	1,092,352	8.3	2.6
Great Britain and No. Ireland#	G.	1,198,282	468,056	5.0	2.1
Japan (March 31, 1928)	G.	446,284	304,277	3.6	0.6
Netherlands	G.	153,782	84,820	5.6	1.7
New Zealand (March 31, 1928)	G.	53,589	90,963	9.9	10.0
Norway	P.G.	59,327	120,157	14.6	5.0
Poland	P.G.	77,357	80,068	2.5	0.3
Sweden	G.	183,511	283,276	19.7‡	5.5
Switzerland	G.	94,147	129,450	11.9	4.0
United States	P.	9,872,144	8,650,623	21.2	12.2

Note: P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and the Government.

* Partly estimated. # March 31, 1928. ‡ The majority of this development is due to Stockholm.

Telephone Conversations and Telegrams
Year 1927

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent of Total Wire Communications		Wire Communications Per Capita		
				Telephone Conversations	Telegrams	Telephone Conversations	Telegrams	Total
Australia	364,195,000	17,995,000	382,190,000	95.3	4.7	59.6	3.0	62.6
Austria	476,000,000	3,707,000	479,707,000	99.2	0.8	69.5	0.5	70.0
Belgium	157,181,000	5,280,000	162,461,000	96.7	3.3	19.9	0.7	20.6
Canada	2,108,400,000	13,800,000	2,122,200,000	99.3	0.7	221.5	1.4	222.9
Czechoslovakia	213,723,000	4,919,000	218,642,000	97.8	2.2	14.8	0.3	15.1
Denmark	476,955,000	2,152,000	479,107,000	99.6	0.4	136.8	0.6	137.4
France	702,963,000	34,061,000	737,024,000	95.4	4.6	17.2	0.8	18.0
Germany	2,244,886,000	37,679,000	2,282,565,000	98.3	1.7	35.5	0.6	36.1
Gt. Britain & No. Ireland	1,300,000,000	66,912,000	1,366,912,000	95.1	4.9	28.6	1.5	30.1
Hungary (1926)	118,264,000	5,062,000	123,326,000	95.9	4.1	14.1	0.6	14.7
Japan	2,586,053,000	61,119,000	2,647,172,000	97.7	2.3	42.3	1.0	43.3
Netherlands	443,000,000	5,202,000	448,202,000	98.8	1.2	58.4	0.7	59.1
New Zealand	256,733,000	7,007,000	263,740,000	97.3	2.7	178.9	4.9	183.8
Norway	212,000,000	3,586,000	215,586,000	98.4	1.6	76.2	1.3	77.5
Sweden	696,785,000	3,981,000	700,766,000	99.4	0.6	114.6	0.6	115.5
Switzerland	176,434,000	2,948,000	179,382,000	98.4	1.6	44.3	0.8	45.1
United States	26,200,000,000	214,403,000	26,414,403,000	99.2	0.8	224.7	1.8	226.5

Note: Telephone conversations represent completed local and toll or long distance messages. Telegrams include inland and outgoing international messages.

Telephones in United States—Distribution by States*
January 1, 1923 and 1928

State	Number of Telephones	
	Jan. 1, 1923	Jan. 1, 1928
Alabama	84,401	121,115
Arizona	24,353	33,194
Arkansas	99,490	118,178
California	763,638	1,205,466
Colorado	150,652	183,250
Connecticut	205,902	290,873
Delaware	23,534	28,901
District of Columbia	102,231	144,985
Florida	79,657	162,293
Georgia	136,334	173,410
Idaho	48,745	54,822
Illinois	1,283,449	1,685,690
Indiana	508,726	552,249
Iowa	533,347	565,533
Kansas	354,251	393,878
Kentucky	201,545	222,735
Louisiana	87,354	137,610
Maine	113,725	131,367
Maryland	153,790	197,135
Massachusetts	687,700	867,888
Michigan	508,140	711,315
Minnesota	424,777	487,611
Mississippi	63,761	79,861
Missouri	550,980	657,946
Montana	55,115	59,238
Nebraska	273,500	295,274
Nevada	10,313	12,959
New Hampshire	68,874	83,066
New Jersey	383,496	599,336
New Mexico	18,342	21,580
New York	1,780,563	2,595,537
North Carolina	116,129	160,507
North Dakota	77,586	86,198
Ohio	962,837	1,122,036
Oklahoma	222,889	278,912
Oregon	146,847	185,171
Pennsylvania	1,085,651	1,393,338
Rhode Island	92,766	114,944
South Carolina	54,078	64,616
South Dakota	101,555	107,641
Tennessee	171,413	220,559
Texas	462,424	614,657
Utah	53,261	63,106
Vermont	54,530	60,793
Virginia	155,490	183,698
Washington	238,275	299,109
West Virginia	116,081	146,677
Wisconsin	429,949	518,461
Wyoming	24,949	28,049
United States	14,347,395	18,522,767

* As reported by the United States Department of Commerce, Bureau of the Census.

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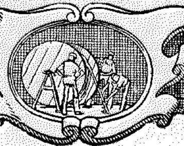

ELECTRICAL COMMUNICATION

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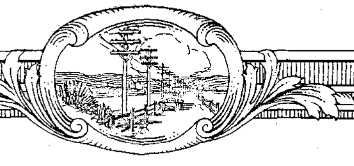

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Volume VIII JANUARY, 1930 Number 3

CONTENTS

Public Address Systems in the Barcelona and Seville Exhibitions 135
By Santiago Herrera Serra

In Memoriam, Dr. M. Merker 139

Calculation of the Articulation of a Telephone Circuit from the Circuit Constants 141
By John Collard, A.C.G.I.B.Sc. (Eng.), A. M. I. E. E.

The Training of Local Staff in Ceylon for Communication Engineering Works 164
By E. Harper, M. I. E. E., Mem. I. R. E.

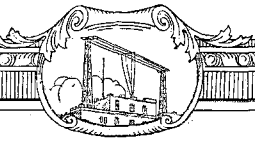
A New Contribution to the Rational Design of Telephone Cables 173
By D. P. Dalzell

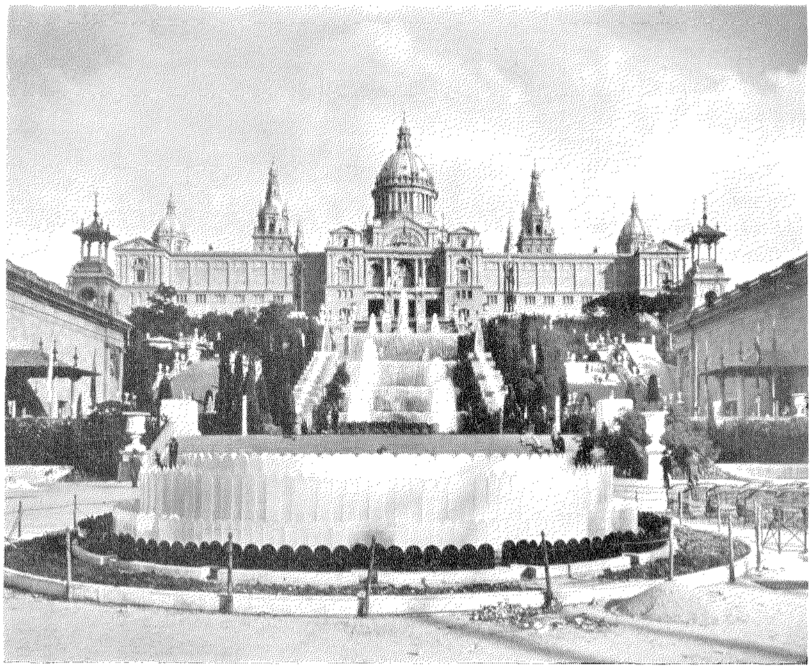
Czechoslovakian Cable System 179
By F. J. Stringer, W. F. Marriage and E. L. E. Pawley

Lightning Damage to Toll Cable 194

The London-Paris-Madrid Telephone Service 196
By L. G. Freeth

Electrical Communication in 1929 202





Main Entrance to the Barcelona Exhibition

Public Address Systems in the Barcelona and Seville Exhibitions

By SANTIAGO HERRERA SERRA

Standard Eléctrica, S. A. Madrid

THE Public Address System is now an indispensable feature of large public gatherings. Among its latest applications in Europe are those at the exhibitions at Barcelona and Seville, which were opened in May this year.

In Barcelona, as most of the projectors were to be located in the interiors of buildings, it was possible to use a large number of projectors in parallel operating at a relatively low transmission level. In Seville, however, where all the projectors were required to be in the open, and none inside the pavilions, a less number of projectors, operating at relatively high level, were employed.

The total output required was about the same in each case, and necessitated three complete No. 1 Public Address Equipments for each exhibition. These installations are therefore among the largest ever made. Figure 1 shows part of the area covered by the projectors at the Barcelona exhibition, Figure 2 the Public Address Equipment at Seville, and Figure 3 a Projector Tower at Seville.

Provision was made for connecting the systems to the local broadcasting stations, so that the input to the stations might be taken and controlled direct from one of the output circuits of the Public Address System without duplicate microphones. In this way, utterances and performances at the openings of the exhibitions were transmitted throughout Spain for broadcasting from all Spanish radio stations.

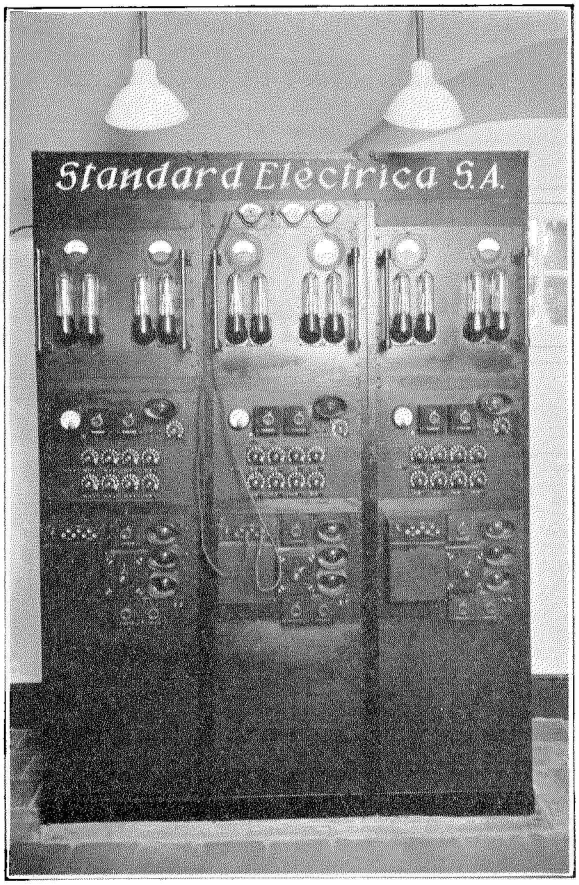


Figure 2—Public Address Equipment—Seville.

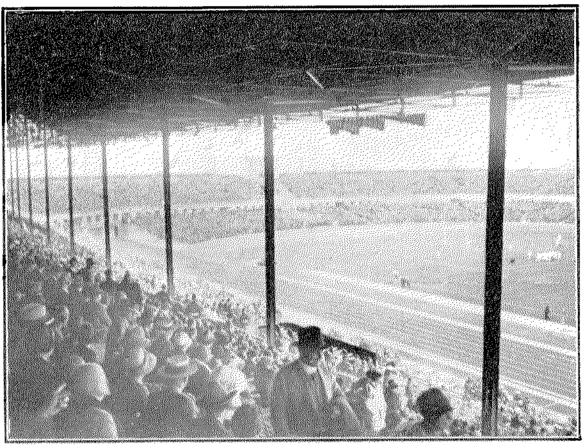


Figure 1—Barcelona Stadium.

As the installation of the Public Address equipments and lines at both exhibitions was carried out in a similar manner, a brief description of that in the Seville exhibition will suffice to explain their new features. It may, however, be here remarked that the organisers of both exhibitions were satisfied with the successful operation of the system, particularly as it had

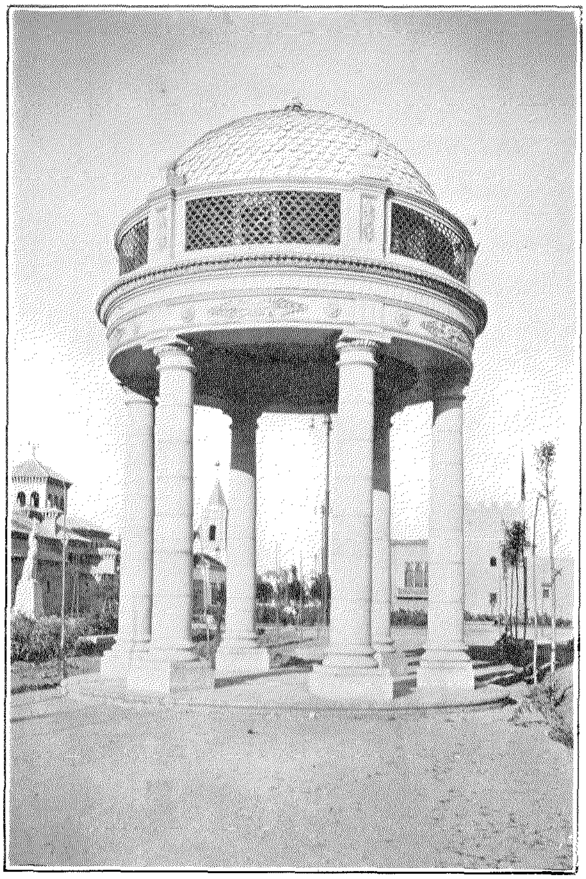


Figure 3—Projector Tower—Seville.

been installed at short notice and had to cover the greater part of the exhibition and reproduce speeches, concerts and announcements to a number of points in the exhibition grounds.

Having decided upon three No. 1 equipments, the question arose whether they should be installed separately or together. Separate installation would have had the advantage of economy in lines—a very important item, since all lines had to be underground—and in addition it would have allowed direct input from the microphones and good subdivision of the projector groups at small cost. These considerations, however, were not sufficient to justify separate installations, since it was seen that the system of control and personnel required would have to be very complicated to give the system the necessary flexibility. Accordingly, the three equipments were installed together, and the ease of control and facility of interchange of the different parts of the equipments fully justified that satisfactory arrangement.

The lines to the microphone positions presented a further problem. With the large number of positions required, the installation of separate lines to each position, while giving central control, would have been very expensive, so that a system of three separate lines, each connecting a group of positions, was adopted. Each microphone is connected when required to the line by a switch at the microphone position, controlled by an operator who is in communication with the central installation through a selective signalling system connecting the different positions to the central unit. To give the operator in the central station greater freedom of movement, the service communication lines terminate in a loud speaker in the control room.

For all the lines, 0.8 mm. and 1.6 mm. rubber insulated lead covered cables were used, laid direct in soft earth, and protected with bricks. To avoid interference, the projector lines were

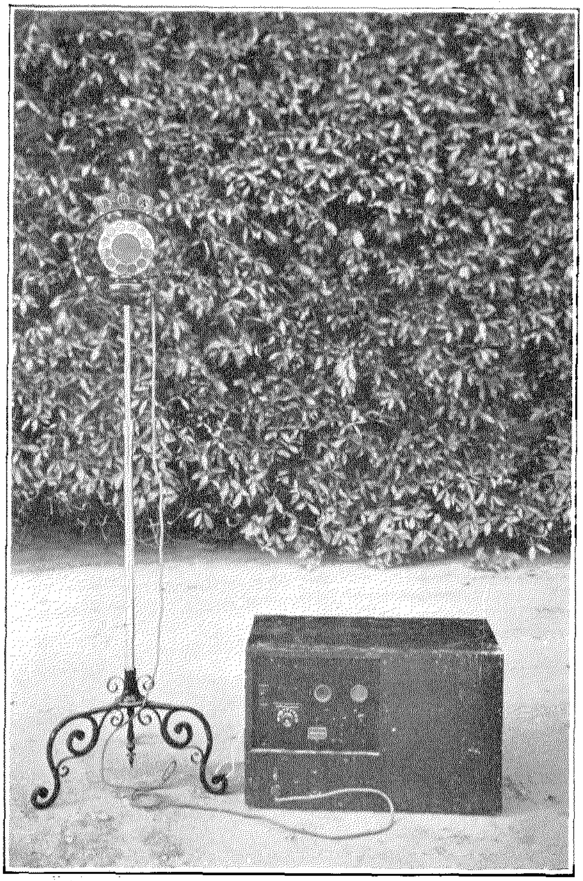


Figure 4—Preliminary Amplifying Unit.

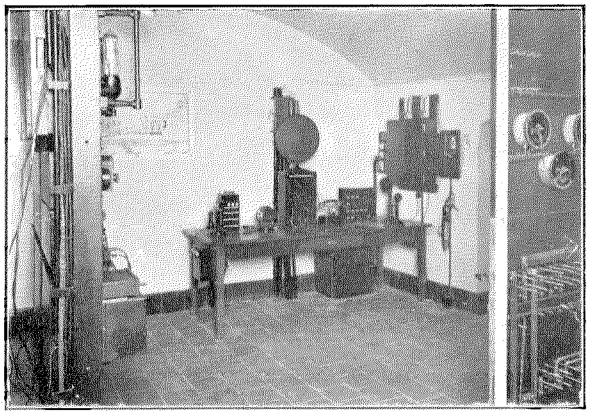


Figure 5—Control Desk—Seville.

installed apart from the other lines and shielded with heavy iron tubes wherever they are close to the microphone and service lines.

Between the microphone positions and the Public Address equipments a preliminary amplifying unit is used. In this way, instead of the three microphone lines at a low energy level which would be used normally, only two lines are required and these have the energy level high enough to overcome parasitic noises due to inductive effects. This amplifier is shown in Figure 4 mounted in a special case containing plate and filament batteries with jacks for the microphone, pilot light and terminals for connecting to the main microphone circuit and pilot light circuit.

The pilot light line is in reality a spare microphone line exactly similar to the microphone lines and installed in parallel with them, but used temporarily for supplying the pilot light on the amplifier when the main microphone line is connected to the Public Address equipment and amplifier ready to operate. If this spare circuit should be required for the microphone, supervision would be made over the service telephone line.

The three microphone lines are connected to the speech input side of the Public Address equipments through a key box shown at the left side of Figure 5. This arrangement allows any combination of the three equipments with the microphone lines to be so made that the inputs of all equipments may be connected to one microphone, or individually to different microphones. The keys also control the pilot signal lines.

For similar reasons, the projector lines are not directly connected to the volume control panels, but to a small pony board where they terminate in cords and plugs making connection with the volume control panel groups through the pony board jacks. The monitoring loud speaker is also connected by a cord circuit through this board, and is arranged to give complete interchangeability to the system.

The cord of the monitoring loud speaker of the announcer is connected to a cut-off relay which operates when the announcer's microphone is connected to the System, to avoid the pick up by the microphone of sounds from the monitoring Loud Speaker.

The supply of energy for such a large installation was no small matter, and it was at once realised that it would be uneconomical from the points of view of first cost and maintenance to

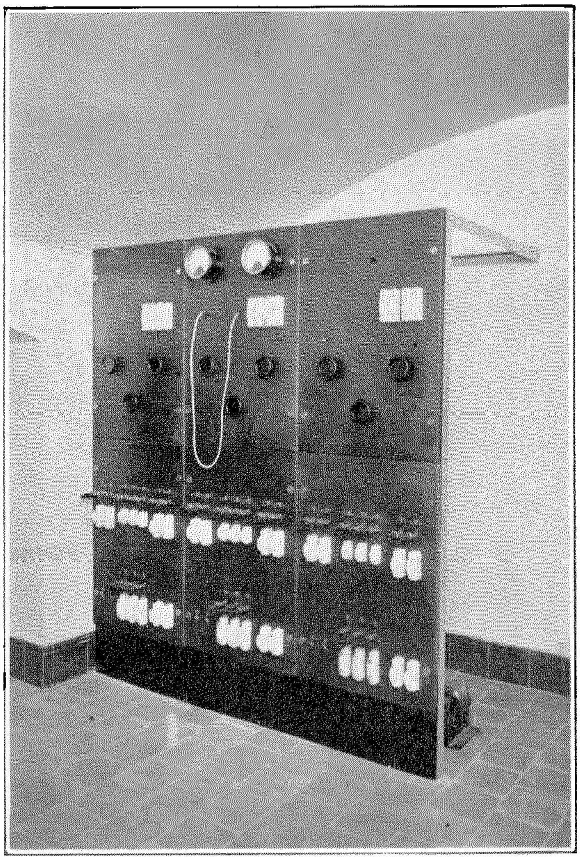


Figure 6—Power Panel—Seville.

follow the usual practice of using a system of batteries for the filament and plate circuits of the valves. Moreover, the authorities wished to be able to use the three equipments separately for other public gatherings when the exhibitions were finished. This would have required three separate battery systems which would have had to be of such capacity that the three Public Address Systems could be supplied from two battery systems in order to avoid the possibility of breakdowns on the power side of the installations.

Three motor generator groups of Spanish manufacture were therefore provided, each group being mounted on one bed plate, and made up as follows:

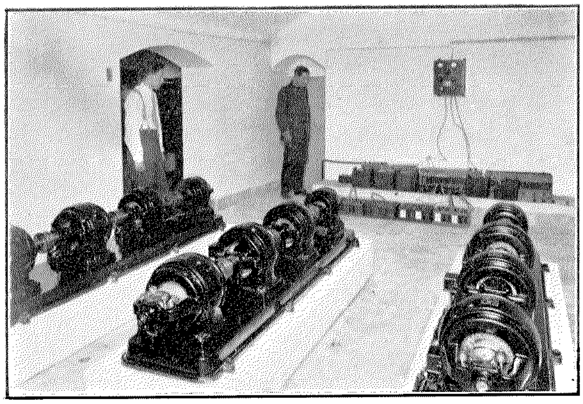


Figure 7—Machine Room—Seville.

One 3½ H. P. Three phase squirrel cage motor.

One Dynamo 15 Volts 25 amperes for the filament current.

Two Dynamos each 400 Volts 1 ampere connected in series for the plate circuits.

Filters composed of inductances and condensers were provided, and batteries floating between the generators and filaments ensured stability in the valve operating conditions. As two of these groups were able to supply the three equipments in case of emergency, a reserve group was not installed. The power panel for the generator groups is shown in Figure 6. Regulation of the filament and plate voltages was very easily obtained by means of the rheostats, controlling the dynamo fields.

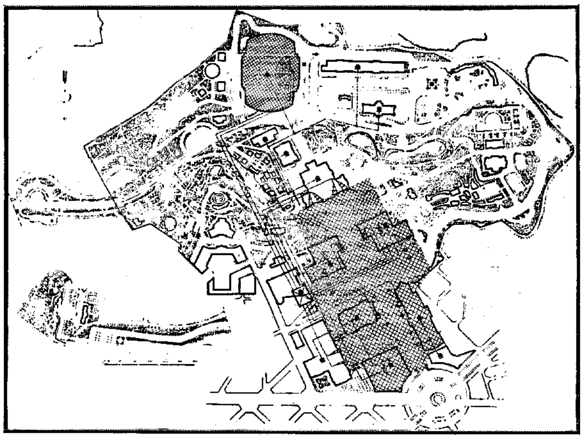


Figure 8—Plan of Barcelona Exposition and layout of public address system.

The machine room is shown in Figure 7. The Tungar charging unit, seen in the background of this illustration, is used for charging the preliminary amplifier batteries during the night.

Since the inauguration of the two exhibitions, the systems operated almost continuously during the hours of opening to the entire satisfaction of the organisers.

The exposition ground plans and the layouts of the Public Address Systems at Barcelona and Seville are shown in Figures 8 and 9. The engineering and planning of these two installations were carried out by Standard Eléctrica, S. A.

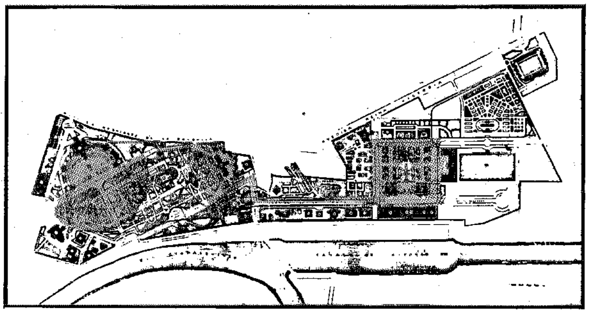


Figure 9—Plan of Seville Exposition and layout of public address system.

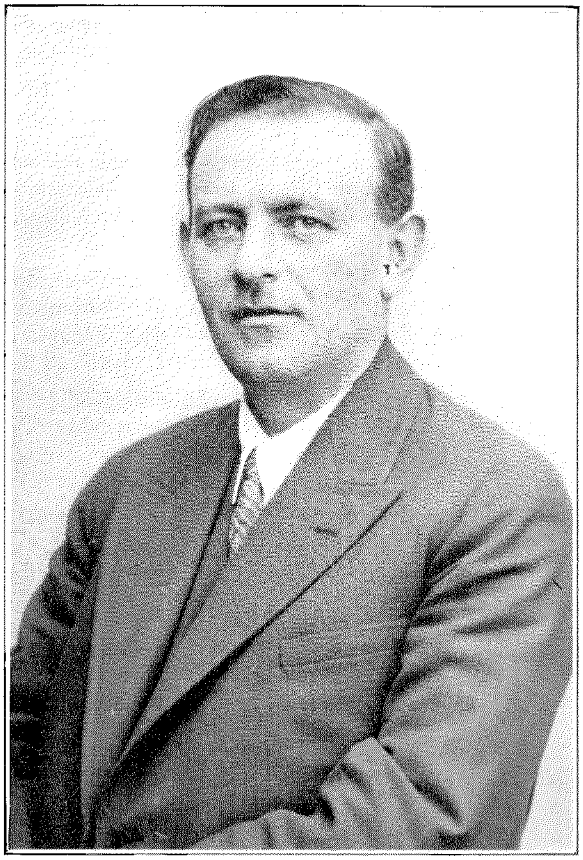
In Memoriam

DR. M. MERKER'S death in Paris on June 28th last is a loss which ELECTRICAL COMMUNICATION records with deep regret. He was of Polish nationality, for he was born in Warsaw in 1886. After completing the educational course of the Mlawa High School, in Warsaw, he applied himself from 1908 to 1910 to more advanced studies at the University of Liége. During 1911 and 1912 he was instructed in electrotechnique at the Institute Montefiore associated with the University of Liége. Thereafter he read mathematics and physics at that university, but owing to the war he did not terminate his studies until 1920, when he received the degree of Doctor of Physics and Mathematical Sciences. In November, 1921, he joined the Bell Telephone Manufacturing Company. He continued in Antwerp until he was transferred to the Paris Laboratories, on December 1, 1928.

Dr. Merker is best known in the world of telephony for his applications of mathematics to theories of probability related to automatic exchanges. His associates interested in those profound problems delighted to work with him, for his assistance was always cheerfully given. His penetrative mind was ever open to suggestions, and his genial nature led him to give them careful and sympathetic consideration.

He early realized that, to obtain the desired results, practical telephony and the theory of mathematics must go hand in hand. In the beginning of his professional career, therefore, when he lacked details of working conditions, he never hesitated to confess that he did not know, and to turn to his associates for information and guidance.

As the author of contributions to the application of the theory of probability to telephony, his name will always be remembered with distinction amongst those who from intricacies derived results of service, in a comparatively simple form, to the engineering art. He soon acquired thorough knowledge of the working of automatic exchanges. His studies in connection with "grading," "slipping," and "splitting" found great practical application in calculations appertaining to the rotary system. Amongst other results, he developed curves for "grading" which can usefully be applied by engineers familiar with traffic and switch calculations.



DR. M. MERKER

Dr. Merker possessed the heritage of his race as a linguist, for in addition to Polish, he had a good working knowledge of Russian, French, German, and English. He started many interesting studies which—without his guidance—will not easily be brought to a successful conclusion. From this brief account of him it will be seen that he was only recently transferred to the Paris Laboratories. For some time he had looked forward to that transfer as he felt that he could be more useful to the Company by devoting his knowledge and time there to the more general problems submitted for solution. Special ability, and love for the work, are two characteristics rarely to be found so closely allied or so strongly developed as they were in him.

To one so devoted to telephony as was Dr. Merker, the records of his published results constitute a tribute to his memory. It is therefore appropriate here to direct attention to the following:

1) Berechnungen der Sprechfrequenzverluste in Schnur stromkreisen mit in Brücke liegenden Scheinwiderständen; Elektrische Nachrichtentechnik. Vol. 3, No. 5, May, 1926.
2) Some notes on the use of the probability theory to determine the number of switches in an Automatic Telephone Exchange. The Post Office Electrical Engineers' Journal, Vol. 17, Part I, April, 1924.
3) Quelques remarques sur l'emploi du calcul, des probabilités dans la détermination du nombre des sélecteurs d'un bureau téléphonique automatique. Annales des Postes, Télégraphes et Téléphones No. 3, 1924.
4) Application du calcul des probabilités à la détermination du nombre d'organes et leur mode de connexion dans un bureau de téléphonie automatique. Revue Générale de l'Electricité, April 20 and 30, May 7 and 14, 1927.
5) Notes sur l'application du calcul des probabilités à l'exploitation téléphonique. Revue Générale de l'Electricité, February 21, 1925.
6) Die Berechnung der Wahlerzahl in Selbstanschlussämtern. Elektrotechnische Zeitschrift, October 9, 1924.
7) Application du calcul des probabilités à la détermination du nombre d'organes dans un bureau de téléphonie automatique. Technische Mitteilungen, February, 1928.

Calculation of the Articulation of a Telephone Circuit From the Circuit Constants[1]

By JOHN COLLARD A. C. G. I. B. Sc. (ENG.) A. M. I. E. E.

Development and Research Laboratories, International Telephone and Telegraph Corporation.

SINCE the function of a telephone circuit is to transmit speech from one subscriber to another, the final criterion of the performance of the circuit is the grade or quality of speech delivered at the end of the circuit. The quantity usually employed as a measure of the quality of speech is known as the articulation, and is defined as the percentage number of random syllables correctly received over the circuit. Once a telephone circuit has been set up, articulation tests can be carried out, and the value of articulation so obtained. Similarly, if an existing piece of apparatus is to be substituted for another in the same circuit, and it is required to know the effect on articulation of this change, the answer can be determined by carrying out a series of articulation tests. There are many instances, however, where it is required to know the articulation of a circuit before setting up that circuit or before making up a certain piece of apparatus. In these cases it is impossible to carry out articulation tests, since the circuit or apparatus is not in existence. Some method of predetermining the articulation is, therefore, required, and the object of this paper is to develop a method by means of which the articulation of the circuit can be calculated from a knowledge of its constants.

A detailed study of speech and hearing has been carried out, and as a result, a complete and rigid theory has been built up in connection with the transmission of sounds over a telephone circuit. From this theory a series of algebraic formulae have been worked out which enable the articulation of the circuit to be calculated from a knowledge of such factors as the attenuation of the circuit and the amount of noise present in the circuit.

Speech is carried over a telephone circuit by means of certain frequency components, produced by the voice of the speaker at one end of the circuit, and received by the ear of the listener at the other end. Owing to effects such as attenuation and line noise in the circuit, these components reach the listener in a more or less distorted manner. It is only those components which reach the listener's ear at a level above his threshold of hearing, which can play any part in enabling him to understand what has been said. The method consists, therefore, essentially of a determination, for any given case, of which of the frequency components are above threshold at the receiving end. Then from the general study of speech, the relative importance of the different frequency components is determined, and hence the value of articulation for the circuit can be worked out.

The theory has been presented in such a form that its practical application to any given case requires only about half-an-hour, as compared to a total time of about 50 hours, which would be required if the same result were obtained by actual measurement. A comparison is given between the calculated and measured results for a number of actual cases, and the results show that the theory is capable of giving results in close agreement with practice.

This method of calculating articulation has the following applications:

(1) It enables articulation or intelligibility of the telephone circuit to be calculated from the knowledge of the circuit constants.

(2) It enables the effect on speech of any proposed change on a circuit or piece of apparatus to be predetermined, without the necessity of lengthy tests.

(3) It enables the effect on speech of various quantities, such as crosstalk attenuation and noise to be determined, and, therefore, allows limiting values of these quantities to be fixed.

Introduction

Since the object of a telephone circuit is to transmit speech from one subscriber to another,

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[1] Presented before World Engineering Congress, Tokyo, Section 6, October 30, 1929.

the final criterion of the performance of that circuit must always be the grade or quality of speech delivered at the end of the circuit.

Several quantities have been used as a measure of the quality of the speech transmitted over a telephone circuit amongst which may be mentioned the intelligibility and the word, syllable or sound articulation. In a previous paper (^{12}) by the author, it was shown that a perfectly definite relation existed between all these quantities, and algebraic formulae were developed from fundamental considerations giving each of the above quantities in terms of the ideal sound articulation.

The value of articulation obtained over a given telephone circuit by a given testing crew depends partly on factors such as distortion, which are functions of the circuit characteristics and partly on factors such as faulty pronunciation, which are functions of the testing crew. The factors depending on the testing crew vary from crew to crew, so that the articulation obtained over a given circuit will also vary from crew to crew. To avoid this difficulty and to obtain a quantity which is a true measure of the characteristics of the circuit alone, the ideal sound articulation is used. This quantity is the value of sound articulation that would be obtained if it were possible to use an ideal testing crew which never committed faults such as careless pronunciation or inattention during a test. The value so obtained is consequently a true criterion of the circuit characteristics and does not depend on the characteristics of the testing crew. For these reasons it is proposed in the work described here to deal only with the ideal sound articulation.

The word "sound" is here used to denote any single vowel or consonant sound of speech, of which a list is given later. For the purposes of articulation testing these sounds are formed into syllables of the form, consonant-vowel, vowel-consonant or consonant-vowel-consonant, which are called over the circuit to be tested. Since the object of an articulation test is to obtain a measure of the quality of speech transmission obtainable over the circuit, the frequency of occurrence of the different sounds in the articulation lists is arranged to be the same as that for speech.

Once a circuit has been set up, articulation tests can be made on it and the value of sound articulation obtained. Similarly, if an existing piece of apparatus is to be substituted for another in the same circuit, and it is required to know the effect on speech of this change, the answer can be determined by carrying out actual articulation tests.

There are many instances, however, in which it is desired to know, before setting up a given circuit or before making a certain piece of apparatus, what quality of speech will be obtainable over the given circuit or with the given piece of apparatus. In these instances it is obviously impossible to carry out tests since the circuit or apparatus is not in existence. Even in cases where it is possible to determine the articulation by actual tests it will often be quicker, and certainly will be more economical, to determine the value by calculation. In this connection it is interesting to note that Fletcher states (^{13}) that to obtain a value of articulation with a probable error of one per cent it is necessary to call 5,000 syllables over the circuit. In any investigation where a number of alternatives are to be compared and, say, ten values of articulation are to be determined, about 50,000 syllables would have to be used or, including the calibration of the testing crew, about 60,000 syllables. Since the syllables are called at the rate of about 20 per minute, a total time of 50 hours would be required for the calling alone, quite apart from the preparations, checking of lists, etc.

Some method of predetermining the articulation is therefore required and the object of this work was to develop a method by which the articulation of a given telephone circuit could be calculated from a knowledge of the circuit constants.

A complete description of the method together with the mathematical development of the basic theory is given in the sections, *Development of Formulae* and *Determination of Constants*. Owing to the large number of details in connection with speech and hearing which have to be mentioned in describing the mathematical development of the theory, these sections tend to make the method of calculating articulation appear much

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[12] For numerical references in parentheses, see *Bibliography*.

more complicated than it really is. For this reason this paper has been arranged in the following way. In the section *Practical Application* is given a description of the way in which the method of calculating articulation is applied to a practical case, and a simple example is worked out. Then in the section *General Theory* a general description of the theory is given in non-mathematical language. This is followed by a complete description of the development of the theory in the section *Development of Formulae.*

The formulae involved in this method for calculating articulation contain certain constants whose values depend on certain characteristics of speech and hearing. Part of the work therefore consists of the evaluation of these constants.

It was estimated that this part of the work might require a period of one or two years before all the necessary data could be obtained. Before deciding whether it was worth while carrying out this work, some indication was naturally required of the accuracy with which the theoretical formulae could be applied to practical cases. It was decided, therefore, to carry out an approximate evaluation of the constants using such information on speech and hearing as had already been published. If the results obtained by the theory, using these approximate values of the constants, were reasonably accurate, the work required for the more accurate evaluation of the constants would be undertaken. The approximate determination of the constants is described in the section *Determination of Constants.* It should be realised, in judging the accuracy with which the measured values of articulation agree with the calculated values, that the latter are based only on the approximate determination of the constants, so that differences are likely to occur in some instances. Even so, the agreement between the measured and calculated results is so close as to provide convincing evidence as to the accuracy of the theory, and the work required for the accurate determination of the constants has consequently been undertaken.

Some of the physical data is original, but a large part of it has been obtained from the many papers published on the subject by various members of the Bell Laboratories in America. In particular considerable use has been made of the book *Speech and Hearing* by Dr. Harvey Fletcher, which collects together a very large amount of most useful information on the theory and practice of speech and hearing. A bibliography is given at the end of this paper in which are included all the articles from which information has been obtained.

The whole study has been made in connection with the English language and small modifications may be required to make the method applicable to other languages. The previous study (12) has shown, however, that articulation results for English, French, German, and Italian are in close agreement, so that the whole method, without modifications, can probably be used for these four languages with sufficient accuracy for practical purposes.

Practical Application

Speech is carried over a telephone circuit by means of certain frequency components produced by the voice of the speaker at one end of the circuit and received by the ear of the listener at the other end. If the components arriving at the listener's ear are exactly the same as when they left the speaker's mouth, we might regard the circuit as being perfect. Few circuits reach this high degree of performance and in general the components arriving at the listener's ear are not the same as those leaving the speaker's mouth, for two reasons. Firstly, the overall attenuation of the circuit is different at different frequencies so that the components arrive in a distorted form. Secondly, additional components, which were not originally present, are produced in the circuit, either due to noise or due to overloading of some part of the circuit. The effect of the additional frequencies is, as shown by Wegel and Lane (2), equivalent to raising the threshold values of the ear by a certain number of decibels. It is therefore equivalent to adding the same number of decibels to the attenuation of the circuit.

Assume that it is required to calculate the articulation for a given telephone circuit whose air to air attenuation is given for different frequency bands by column 2 in the following table. Assume also that the threshold shift at the different frequencies, due to line noise, is that given in column 3 of the table.

The method of calculating the articulation of the circuit is then as follows: Add directly the threshold shift values, expressed in decibels, to the air to air attenuation values, also expressed in decibels. The result is given in column 4. Then from tables of p Δ b, of which an extract is given in the section *Determination of Constants*, read off the values of the quantity p Δ b corresponding to the values of column 4 for each frequency band. Add up these values for all the frequency bands; this gives a value of b of .4867. From the curve of Figure 1 read off the value of d_i corresponding to the value of b of .4867. This value of d_i is the required value of the ideal sound articulation for the circuit which is therefore 84.3%.

(1) Frequency Region	(2) Air to Air Attenuation (Decibels)	(3) Threshold Shift due to noise (Decibels)	(4) Resultant Attenuation (Decibels)	(5) p Δb.
0– 200	70	0	70	.0036
200– 400	68	1	69	.0300
400– 600	65	5	70	.0883
600– 800	60	9	69	.0858
800–1000	53	13	66	.0698
1000–1200	50	16	66	.0583
1200–1400	55	18	73	.0534
1400–1600	60	19	79	.0383
1600–1800	65	19	84	.0270
1800–2000	69	18	87	.0178
2000–2200	73	18	91	.0076
2200–2400	76	17	93	.0043
2400–2600	79	17	96	.0016
2600–2800	82	16	98	.0007
2800–3000	84	16	100	.0002
			Σ p Δb	.4867

The short time required to calculate a value of articulation in this way is in striking contrast to the long time required to obtain the same value by measurement.

General Theory

The ear is so constructed that, at each frequency, there is a minimum threshold pressure below which no audible sensation is experienced. If a speech component at a given frequency arrives at the ear with a pressure lower than the threshold value at that frequency, then it is not perceived by the listener and can therefore play no part in assisting him to distinguish one sound from another. A given speech component may be reduced below threshold either by being attenuated by some part of the circuit through which it passes, or by being masked by some other frequency due to line noise or overloading in some part of the circuit. The problem therefore resolves itself into two parts, a determination of how many of the speech components, in any given case, reach the listener at such a level as to be above threshold, and the calculation of the articulation from the knowledge of which of the speech components are above threshold.

An examination of oscillographic records and frequency spectra of the various speech sounds (8) (13), shows that each sound consists of a large number of components at different frequencies throughout the audible range.

The prominent frequencies, however, occur in one or more little groups or bands of frequencies. An idea of this will be obtained from Figure 2, which shows the frequency spectrum for an imaginary speech sound. It will be seen that this imaginary sound contains two groups or bands of prominent components. A study of certain data, referred to in the section *Determination of Constants*, has enabled these bands to be determined for all the speech sounds. Some sounds have only one of these bands while others have as many as four or five bands. The frequencies at which these bands occur are different for the different sounds and it is by noting where these prominent bands occur that the ear is able to distinguish one sound from another. For this reason these bands have been called the characteristic bands of speech. The frequency components outside these bands are very small and play practically no part in assisting the listener to distinguish one sound from another. This conception of the characteristic bands of speech is important because the whole theory developed here is based on it.

In a previous paper (12) it was shown that, when random words were called over a telephone circuit, there was a perfectly definite relation between the percentage number of words correctly received and the percentage number of individual sounds received correctly. An algebraic formula was given by means of which the word articulation could be calculated for any given case if the corresponding value of sound articulation was known.

In an exactly similar way a formula can be obtained which will give the relation between the number of sounds a listener will receive correctly and the number of the characteristic bands he will receive correctly. A curve showing the relation between these two quantities is given in Figure 1. If, therefore, we know what we may call the band articulation of a given circuit, i.e., the percentage number of characteristic bands correctly received when an articulation test is made over a circuit, we can immediately determine the corresponding value of the sound articulation. It may at first appear an unnecessary complication to bring in this new quantity, the band articulation, and it may be found a little confusing to think of the listener as receiving the characteristic bands. The reason for introducing the band articulation, however, is that it has a very useful property not possessed by the sound articulation. This property is described in the following paragraphs.

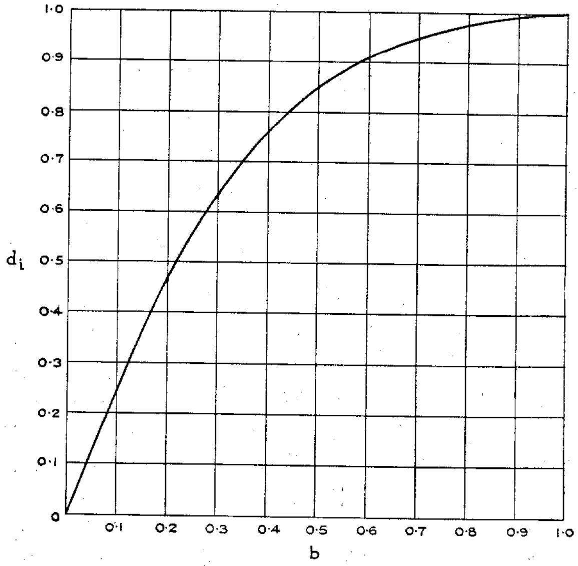

Figure 1

Suppose that a telephone circuit has been constructed which allows all frequency components between f_1 and f_2 to pass without distortion while suppressing all other frequencies, and suppose that under these conditions, when an articulation test is made on the circuit, the average sound articulation is found to be d_{12} and the average band articulation is b_{12}.

Now, suppose that the circuit is changed so that it only passes frequencies in the region f_3 to f_4, and let the sound articulation be d_{34} and the band articulation be b_{34}. The problem now is, if the circuit is again changed so that it will now pass both the range f_1 to f_2 and the range f_3 to f_4, what will be the relation between the new sound articulation d_{1234}, d_{12} and d_{34}, or what will be the relation between the new band articulation b_{1234}, and b_{12} and b_{34}.

The answer to the first question is that there is no simple relation between d_{1234}, d_{12} and d_{34}. There is, however, a simple relation between b_{1234}, b_{12} and b_{34}; it is $b_{1234}=b_{12}+b_{34}$.

It is this property of the band articulation which makes it so valuable as an aid to calculating the sound articulation for a given circuit. It enables us to determine the effect on articulation of the different frequency regions in the audible range. For example, if the sound articulation obtained over a circuit which passes all frequencies from 0 to 1500 periods per second, but suppresses all others, is found to be 63% and the articulation for a circuit passing all frequencies from 0 to 1600 periods per second is 67%, then the corresponding values of the band articulation will, from Figure 1, be approximately 29% and 33%, and the difference will be 4%. This means that the frequency region from 1500 to 1600 periods per second contributes an amount 4% to the band articulation. Hence, since $b_{1234}=b_{12}+b_{34}$, whenever the region 1500 to 1600 is transmitted to the listener it will always contribute this same amount, 4%, to the band articulation.

The value of band articulation for all 100-period frequency regions from 0 to 6000 has been determined by the method outlined above for the region 1500 to 1600 periods per second. Further particulars of this are given in the section *Determination of Constants*.

The method for calculating the articulation is then briefly as follows: The frequency regions which are reaching the listener at a level above threshold are determined, and then the values of band articulation are added together for these regions and so the total value of band articulation for the circuit is obtained. The curve of Figure 1 at once gives us the corresponding value of sound articulation.

This solves one-half of the problem and we are only left with the problem of determining what frequency components reach the listener above threshold. Consider the frequency spectra of Figure 2. Since we are concerned with finding out how many of the speech components are above threshold it is convenient to consider the amplitude of a speech component as being so many decibels above threshold. This has been done in Figure 2 which therefore shows the amplitude of the different components above threshold and not as absolute values. It will be clear that the amplitude of each component depends on two things; (a) the degree of loudness, or the level, at which the sound is spoken, and (b) the threshold curve for the listener. If the speaker calls the sound in a louder voice, all the components in the figure will be correspondingly higher; if he calls in a quieter voice all the components will be lower. If the listener is deaf his threshold values will be high, since he requires a greater pressure to produce an audible sensation, and consequently the height of the components of the sound above his threshold will be very small. If the listener has very good hearing, his threshold values will be low and hence the components will be a long way above his threshold.

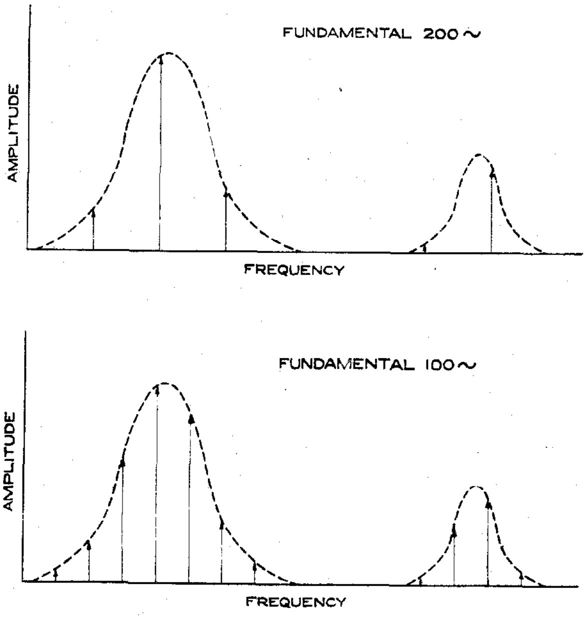

Figure 2

It follows from this that a different frequency spectrum curve like Figure 2 would be obtained for each pair of speaker and listener. A series of such curves is shown in Figure 3 for a one band sound. Owing to these variations from speaker to speaker and listener to listener, it is convenient to deal with the average curve. This is taken as the curve which has as many curves above it as there are below. In other words, if we were to take curves for all possible combinations of speaker and listener, half the pairs would have a curve above the mean and half below. The mean curve is indicated by a dotted line in Figure 3.

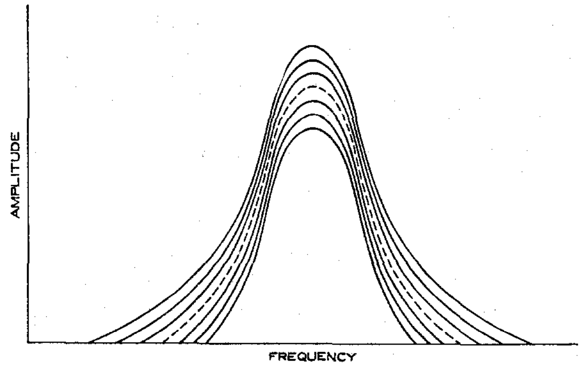

Figure 3

By a method described in the section *Determination of Constants* it has been possible to determine the mid-frequency of each of the characteristic bands of speech and also the level of the mean curve for each band. These values have been plotted with frequency and level as axes and a mean curve has been drawn through the points. (This curve is shown in Figure 4. This curve shows the mean level above threshold at each frequency of the characteristic bands of speech.) The difference between this curve and the dotted curve of Figure 3 is that the curve of Figure 3 is the mean for a particular characteristic band while the curve of Figure 4 is the mean for all bands.

The curve of Figure 4 shows that for a frequency region of, say, f_1 to f_2 the mean height above threshold of the speech components is A decibels. From the definition of the mean curve given above, it follows that if articulation tests were made with all possible speaker-listener combinations, half the combinations would have their speech components in the region f_1 to f_2

at a level above threshold which was greater than A and half would have them at a level less than A. If a circuit were arranged so that in the region f_1 to f_2 it introduced an overall attenuation of exactly A decibels, then the speech components in the region f_1 to f_2 would fail to reach the listener for half the total speaker-listener combinations. In other words, considering the speech components in the region f_1 to f_2, the probability of these components being transmitted for a speaker-listener combination is just one half what it would be if the components were transmitted for all combinations.

If, therefore, the value of the band articulation for the region was found to be b_{12} for the case when all speaker-listener combinations were able to transmit their components, and we wish to know the value of band articulation for this region in the case of a circuit whose overall attenuation is A decibels, we must take $\frac{1}{2}\, b_{12}$ as being the amount that the region f_1 to f_2 will contribute to the band articulation.

The case has been considered here in which the circuit had an attenuation of exactly A decibels. It is clear, however, that a similar state of affairs will exist for any value of attenuation. If the attenuation is less than A, more than 50% of the speaker-listener combinations will succeed in getting their speech components in the region f_1 to f_2 to the listener at a level above his threshold. If the attenuation is greater than A, less than 50% will succeed. In each case the corresponding proportion of b_{12} is taken. The method of determining this proportion for different values of attenuation is given in the section *Determination of Constants.*

In this way the whole problem is solved since we have shown how to determine how many of the speech components reach the listener above threshold and how from this to calculate the articulation.

The application of the method is made very simple by means of the table of which a part is given in the section *Determination of Constants.* This table gives, for each 100 period region, the correct value of band articulation to take for different values of overall attenuation of the circuit.

The method employed for calculating the articulation for a given circuit is then as follows: Having determined the overall air to air attenuation of the circuit for each 100-period frequency region, read off from the table the corresponding value of band articulation. Add up all the values of band articulation, giving the total value of band articulation. Then from the curve of Figure 1 read off the corresponding value of ideal sound articulation.

Development of Formulae

This section gives a detailed description of the fundamental theory and the development of the formulae from which the articulation is calculated. To some extent it repeats what has already been said in the previous section.

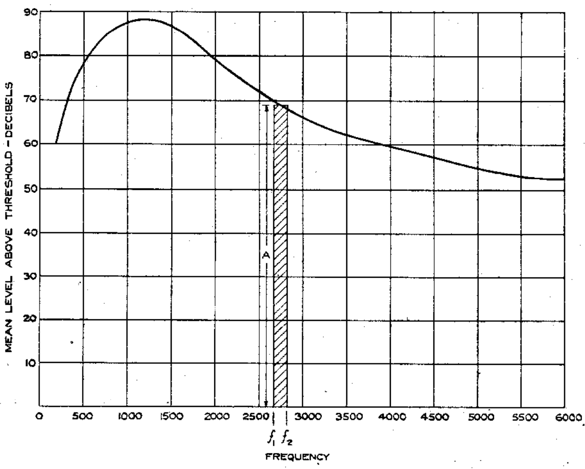

Figure 4

From the point of view of this study it is unnecessary to consider in great detail the different theories that have been put forward to explain the production of speech sounds. These theories have been described and discussed in various publications to which reference is given in the Bibliography. In particular, the book *Speech and Hearing* recently written by Dr. Harvey Fletcher gives a very complete discussion of the subject.

All that is necessary to know here is that a speech sound consists of a large number of components distributed throughout the audible frequency range. Due to the effect of certain resonant cavities of the mouth and throat, some of these components are considerably greater in amplitude than the others, and it is by noting at what frequencies these prominent components occur that the brain is able to distinguish one sound from another. Owing to the fact that the resonance of the mouth and throat give rather flat resonant curves, the prominent components occur in little groups of frequencies rather than as single isolated frequencies. This fact is clearly brought out by the frequency spectra given by Fletcher ([13]) and other authors for the different sounds.

Since it is by the position in the frequency range of these little groups or bands of frequencies that one sound is distinguished from another, they are called the characteristic bands of the sounds. Some sounds have only one characteristic band while others have as many as five.

The actual frequency components present in a given sound differ for different speakers, and even for one speaker they may differ from moment to moment. They always occur, however, in approximately the same frequency region or band. In order to make this clear, Figure 2 has been prepared. This shows two frequency spectra for an imaginary two band sound. In one case the fundamental cord tone of the speaker is assumed to be 200 periods per second. In this case the frequency components occur at intervals of 200 periods. In the second case the fundamental is assumed to be 100 periods per second, and in this case the components occur at intervals of 100 periods. In the second case, therefore, there are twice as many components as in the first case, but, owing to the fact that the prominent components still occur in the same frequency bands, the listener is able to recognise the two spectra as representing the same speech sound.

The next step in the development of the theory of articulation is to consider what happens when a conversation is taking place over a telephone circuit. As each sound is spoken at the transmitting end of the circuit, the various frequency components are transformed into electrical energy, are transmitted to the receiving end of the circuit with varying attenuation, and are finally reproduced at the listener's ear in a more or less distorted condition.

When the attenuation of the telephone circuit varies with frequency, the different characteristic bands arrive at the listener's ear with such distortion that he often mistakes one for another. A further factor tending to make it difficult for the listener to distinguish one sound from another is the presence of additional frequency components due either to noise in the telephone circuit or in the room, or to asymmetric distortion in the circuit.

Assume that, when an articulation test is carried out over a telephone circuit, the probability that the listener will receive a characteristic band correctly is, on the average, b. This means that, if it were possible to transmit the characteristic bands of speech one by one over the circuit, a fraction b of the bands would be correctly received. On the average, therefore, ceah band can be mistaken for $\frac{1}{b}$ other bands.

Now suppose that by some means it were possible to form at random groups of l characteristic bands from the total number of possible bands. These groups would not necessarily be actual sounds although some of them, of course, might happen to be. Suppose, also, that it were possible to produce these groups and to transmit them over a telephone circuit to the listener who has some means of recording what he thinks he has received.

Since b is the average probability of receiving a band correctly, the probability of receiving a group of l bands correctly is b^l. Hence there are $\frac{1}{b^l}$ alternatives for which the correct group of l bands can be mistaken. We can, therefore, consider the listener as setting out mentally the $\frac{1}{b^l}$ alternatives and just selecting one of them at random. The probability of his choosing the right alternative is, of course, b^l.

The next step is to assume that groups of l characteristic bands are being transmitted over a circuit but that, this time, each group is actually a sound and not a random group as before. Assume also that the listener knows he is to receive actual sounds and not random groupings. Then, as before, there will be $\frac{1}{b^l}$ alternatives from which the listener has to select one. This time, however, if he carries out his mental review of the $\frac{1}{b^l}$ possible alternatives, he will notice that some of them are not actual sounds. He thus rejects all these alternatives and is, therefore, left with a certain fraction of the $\frac{1}{b^l}$ alternatives which are actual sounds.

Of the total $\frac{1}{b^l}$ alternatives, one is the correct one and is, therefore, necessarily an actual speech sound. There are thus $\frac{1}{b^l}-1$ alternatives which may or may not be actual sounds. The proportion of these alternatives which are actual sounds depends, of course, on the number of the total possible combinations which are used as sounds. Let this proportion be c_l for sounds having l characteristic bands.

Then $c_l\left(\frac{1}{b^l}-1\right)$ of the $\frac{1}{b^l}-1$ alternatives will be actual sounds. The listener is, therefore, left with the $c_l\left(\frac{1}{b^l}-1\right)$ alternatives, plus the correct one, from which he has to make his choice. The probability that he will choose the correct one is, therefore,

$$\frac{1}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

But the probability of his choosing the correct alternative is the sound articulation d_l, for sounds of l characteristic bands.

Hence

$$d_l=\frac{1}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

From this it follows that the average ideal sound articulation for all sounds is given by the expression

$$d_i=\sum\frac{k_l}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

where k_l is the proportion of sounds in speech having l characteristic bands and b is the average band articulation.

This expression thus gives the average ideal sound articulation for a given circuit in terms of the average band articulation. The problem, therefore, resolves itself into the determination of the band articulation for the given circuit.

A statement was made in the previous section to the effect that, if b_{12} was the band articulation obtained over a circuit so arranged as to pass only frequencies in the range f_1 to f_2, and if b_{34} was the corresponding value for the range f_3 to f_4, then, if b_{1234} was the band articulation when both frequency ranges were passed together, these quantities were connected by the equation

$$b_{12}+b_{34}=b_{1234}$$

No conclusive theoretical proof of this relation has so far been discovered but, as the result of numerous tests, it has been found that this relation does hold in practice, except in certain limited cases which do not usually occur. These cases are mentioned in the section *Determination of Constants.*

In general, therefore, we can take the expression

$$b=\Sigma\,\Delta\,b$$

where Δ b is the band articulation for a small frequency region, and b is the total band articulation.

The factors that determine whether a given frequency region is transmitted from the speaker to the listener are:

(a) The amount of energy in this region produced by the speaker's voice.

(b) The attenuation of the circuit and apparatus transmitting the speech from the speaker's mouth to the listener's ear.

(c) The sensitivity of the listener's ear in the frequency range.

It should be noted that the effects of asymmetric distortion and noise are not considered here; they will be dealt with later.

If we determine the average relative amounts of energy present in the voice at different frequencies and express them as so many decibels above or below some given reference value, and then determine the average sensitivity of the are at different frequencies, also expressed in decibels above or below the same reference value, the difference between these two curves will give the average amount, in decibels, at different frequencies that the energy in the voice is above the minimum amount required to produce an audible sensation. In other words, this average speech level-threshold curve indicates the average amount by which a component of speech at a frequency f_1 must be attenuated before it becomes inaudible. This curve is shown in Figure 4.

If we assume for a moment that for all voices all the components in speech at a given frequency have the same level above threshold and that all ears have the same threshold value, then obviously, if we attenuate a given frequency by an amount greater than that given by the average speech level-threshold curve, that component will be inaudible, and will contribute nothing to the articulation. In order, therefore, to determine the articulation obtainable over a circuit having different amounts of attenuation at different frequencies, all we have to do is to determine what frequencies are attenuated so as to be below threshold, and what frequencies remain above threshold. Then we add up the value of Δ b for the frequency ranges above threshold, and so determine the total value of b for all frequency regions above threshold. Finally, we determine the corresponding value of the ideal sound articulation d_i, by means of the expression

$$d_i = \sum \frac{k_l}{1 + c_l\left(\frac{1}{b^l} - 1\right)}$$

It should be noted that in speaking here of the attenuation of a circuit, what is meant is the air-to-air attenuation of the circuit, so that this value includes not only the attenuation of the telephone circuit itself, but also of the transmitter and receiver.

Actually the method of determining the articulation for a circuit is not so simple as that described above. This is due to the following reasons:

(a) The ear threshold curves for individual listeners differ considerably from the average curve.

(b) The components, at a given frequency, for individual sounds differ from the average value at that frequency for all sounds.

(c) The loudness with which a speaker talks varies from speaker to speaker, and even in the case of a given speaker the loudness will vary from time to time.

The result of all these effects can best be understood by considering a circuit arranged to pass only those frequency components within a range f_1 to f_2. Assume that a number of different speakers are taking it in turn to talk over the circuit, and that a number of listeners are taking it in turn to listen. Then assume that the attenuation of the circuit in the range f_1 to f_2 is gradually increased from zero to a very large value.

At first when the attenuation is small the components between f_1 and f_2 of the different sounds will be heard by all listeners and for all speakers. As the attenuation is increased those sounds which have only small components in the range f_1 to f_2 will fail to be heard, and even some of the louder components will fail to get through if they happen to be spoken by someone who speaks in a quiet voice, or if they happen to be received by someone who is rather deaf.

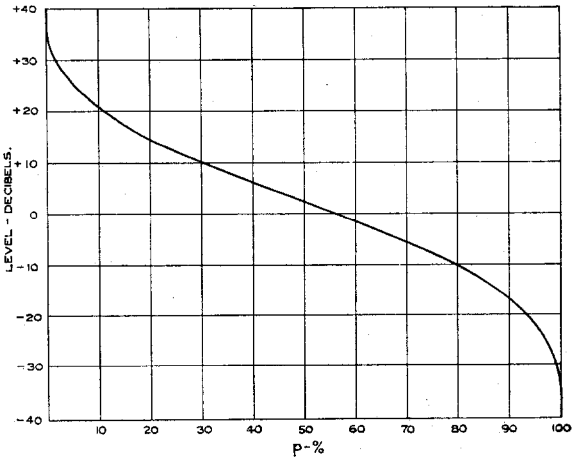

Figure 5

As the attenuation is increased, more and more of the components will fail to get through until finally the attenuation will be so great that no sounds at all will get through, even with the loudest speaker and the listener with the most acute hearing.

If we were to carry out an experiment of this nature, and were to determine for each level the percentage number of components that get through, we could plot a curve showing the number of components as a function of the level.

Such a curve is shown in Figure 5, the level in this case being expressed as so many decibels above or below the mean level above threshold.

The procedure in determining the articulation for a given circuit is then as follows: Divide the frequency range up into a number of small intervals, say, 100 periods. Consider the curve given in Figure 6, where Curve No. 1 is the average speech level-threshold curve given in Figure 4. Curve No. 2 is the air-to-air attenuation curve of the given circuit.

Consider one of the 100 period frequency bands f_1 to f_2. The ordinate A gives the average level of speech above threshold in this range f_1 to f_2. Ordinate C is the overall attenuation in this range introduced by the telephone circuit. Hence $B=A-C$ is the average level above threshold at which the speech arrives at the listener's ear.

Now, from the curve given in Figure 5, we can determine what proportion p of the components in speech between f_1 and f_2 are above threshold when the mean level in that range is B decibels above threshold. Since, for the interval f_1 to f_2, only p of the speech components are above threshold and b_{12} is the value of band articulation for the interval f_1 to f_2 when all components in the interval are above threshold, the probability of receiving a characteristic band correctly in the present case is pb_{12}.

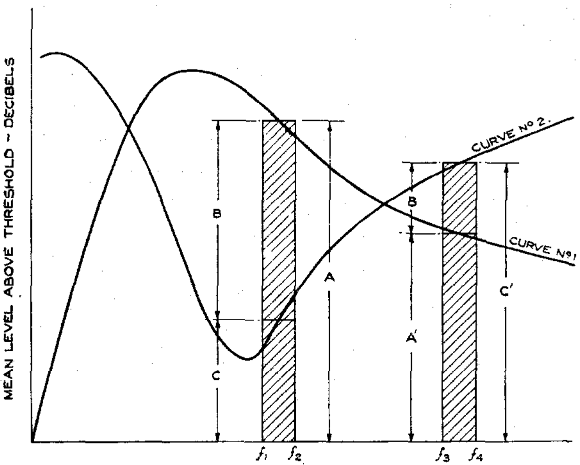

Figure 6

Hence the total band articulation is given by the expression

$$b=\Sigma\ p\ b$$

Having obtained the value of b in this way the corresponding value of d^i is obtained from the expression

$$d^i=\sum\frac{k_l}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

So far only the effect of attenuation on the articulation of the circuit has been considered.

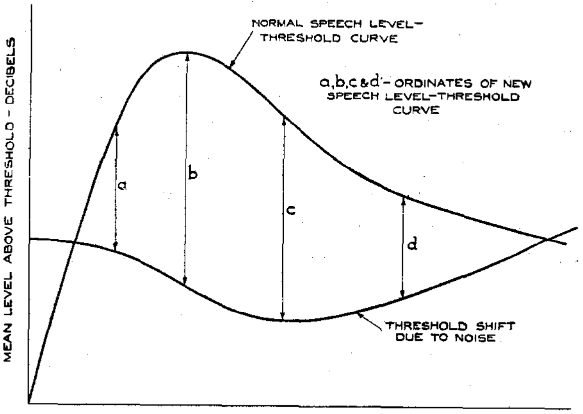

Figure 7

A second factor materially affecting the articulation is the presence of noise in the circuit due to crosstalk from some other circuit, induction from neighbouring power systems, bad contacts in some part of the circuit, or to some other cause.

Wegel and Lane (2) have shown that if a single frequency is introduced into the ear the effect is to raise the threshold for other frequencies in the neighbourhood. In other words, the amount of the second frequency which is required to give an audible sensation is greater when the first frequency is present than it is when the second frequency is introduced into the ear alone. The effect of a single frequency component on the ear is to set the basilar membrane into vibration. The amplitude of the vibration of the membrane is greater at one point and falls off on either side of this maximum point. This point of maximum amplitude of vibration varies according to the frequency which is causing the vibration.

Since the effect of introducing frequency components into the ear is to shift the threshold value by different amounts at different frequencies, the effect of noise on articulation can be taken into account by determining the amount of threshold shift produced by the noise. This modified threshold curve is then used to determine the speech level-threshold curve instead of the normal threshold curve used in Figure 4. In other words, a threshold shift of, say, 50 decibels at a given frequency is equivalent to increasing the attenuation of the circuit at that frequency by 50 decibels.

The threshold shift produced by a given complex tone can either be measured by an exploring tone, or, if the frequency spectrum of the noise is known, an approximate idea of the masking at various frequencies can be obtained in the following way:

The resultant masking of a complex tone is due, of course, to the combined effect of the masking by the individual frequency components. The threshold shift at different frequencies due to a given frequency at a given level can be obtained from the masking curves of Wegel and Lane. The problem is, therefore, how are the threshold shifts at a given frequency due to several different frequency components to be combined to give the resultant threshold shift.

Figure 8 represents what happens when an exploring frequency f_2 is used to determine the amount of masking at f_2 due to the frequency f_1. The level of the exploring frequency f_2 is increased until it is just audible in the presence of f_1. The height OB represents the amplitude of vibration of the basilar membrane at the point O due to the masking frequency f_1. The point O is the point of maximum amplitude of vibration of the membrane for the frequency f_2. Since the basilar membrane is already in movement at the point O due to the presence of f_1, the introduction of the frequency f_2 has the effect of increasing the amplitude of vibration at the point O. If the level of f_2 is increased until f_2 is just audible in the presence of f_1, then OA is the amplitude of vibration due to f_2 which, when added to the existing amplitude of vibration OB, produces an increase in vibration which is just perceptible. Wegel and Lane state that the value of OA is approximately equal to OB. This means that the amplitude of vibration of the basilar membrane at a frequency f_2 due to a frequency f_1 is equal to the amplitude of vibration produced by an exploring frequency f_2 at such a level that it is just perceptible in the presence of f_1. The amplitude of vibration of the basilar membrane V in terms of the threshold amplitude, is, therefore, determined from the expression $20 \log_{10} V = S_t$, where S_t is the threshold shift given by the masking curves.

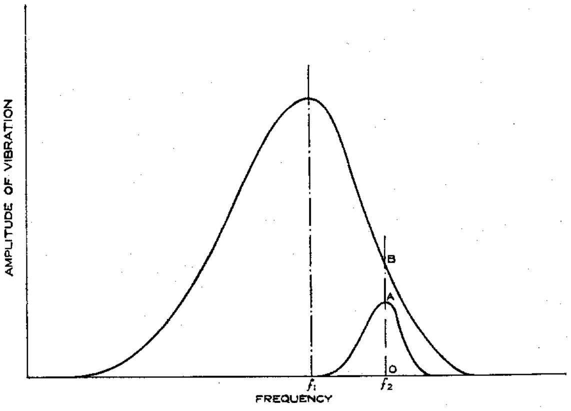

Figure 8

Having determined V for the different frequencies present in the masking tone, the resultant value V^1 is found by summing as the square root of the sum of the squares.

The corresponding value of resultant threshold shift S_t^1 is then determined from the expression $20 \log_{10} V^1 = S_t^1$. This procedure is repeated for any given point along the basilar membrane and so the resultant threshold shift frequency curve is obtained.

The effect of noise, then, is to raise the threshold by different amounts at different frequencies and so produce a new threshold curve. This effect can, therefore, be allowed for by taking this new threshold curve, instead of the normal one, when constructing the speech level-threshold curve.

In other words, the threshold shift in decibels at each frequency is added to the corresponding air-to-air attenuation in decibels. An example is shown in Figure 7.

In addition to the effect of ordinary distortion and noise on articulation, there is a third factor whose effect is rather in the nature of a combination of the first two. This third factor is asymmetric distortion which occurs when some part of the circuit departs from a linear characteristic. Some of the common causes of asymmetric distortion are overloading of iron cored coils and vacuum tubes, carbon microphones and overloading taking place in the ear.

Very little has been published on the question of asymmetric distortion and, owing to lack of time, not much work has been done on this subject in connection with the present study. The method of taking into account the effect on articulation of asymmetric distortion is therefore not very fully developed. So far as it has gone, however, it has given reasonable results, so a short description has been given here as a matter of interest.

The question of asymmetric distortion and its effect on articulation is a very important one, since all commercial telephone circuits are subject to a certain amount of such distortion. Further work on this subject is therefore being planned. In general, it can be said that the effect of asymmetric distortion is to produce in the circuit or ear all the harmonic series of any frequency originally present. As the amplitude of the original frequency increases, the amplitude of the harmonics due to asymmetric distortion increases very rapidly until the latter may become as large as the original frequency.

The effect of asymmetric distortion is similar to that of noise; that is to say, the harmonics cause masking of the speech components. There is the essential difference, however, that the effect varies with the volume of speech and depends on the particular sound being spoken. The masking curves published by Wegel and Lane(2) show that the masking effect of a given frequency on frequencies below it is small compared with the effect of the frequency on frequencies above it. This effect is due to the asymmetric distortion taking place in the ear.

Except at very large volumes, the amplitude of one frequency must be considerably greater than that of the second before the first will cause any appreciable masking of the second. We should expect, therefore, that it would only be in the case of those sounds that have a high level low frequency component and a low level high frequency component that the effect of asymmetric distortion would be noticeable. From an inspection of Fletcher's curves(13) of articulation against level for individual sounds, together with the list of frequencies and levels for the characteristic bands given in this paper, it will be seen that this is the case. Sounds having only one characteristic band do not, therefore, show signs of the overloading of the ear, nor do sounds in which the different bands have about the same level.

From a knowledge of the relation between input and output voltage at different levels for any piece of apparatus causing asymmetric distortion, it is possible to calculate by simple mathematical formulae the magnitude of the different harmonics caused by asymmetric distortion when a given voltage is applied to the apparatus. These formulae are too well known to require to be given here. Once the magnitude of the harmonics is known, the masking effect when these harmonics are introduced into the ear is determined in the same way as for noise.

The effect of asymmetric distortion has only been considered, so far as this study has gone at present, in connection with the overloading effect taking place in the ear itself. In this case the method has given good results, but as to whether it would give equally good results for other types of asymmetric distortion has not yet been tried owing to the lack of the necessary data.

The method employed in connection with the overloading of the ear was as follows: Since the maximum level of speech above threshold occurs at about 1200 periods and is about 88 decibels, as shown in Figure 4, the effect of asymmetric distortion was considered as though it were due only to a 1200 period component. For any particular sound this will not give correct results, but on the average it does give results which agree with practical measurements. The level at which this 1200 period component arrives at the ear for any given circuit is 88 decibels minus any attenuation at that frequency produced by the circuit. The masking of other frequencies produced by this 1200 period tone is determined from the curves of Wegel and Lane, and the effect on articulation is determined in the same way as that described for noise. It should be noted, however, that the effect of asymmetric distortion only occurs in the case of about 10 of the 36 sounds, so that a resultant value of b is obtained by taking 10 times the value of b calculated with asymmetric distortion and 26 times the value without asymmetric distortion, adding the two together and dividing by 36. It will be obvious that there are a number of approximations and assumptions used in this method, but it would appear that they are permissible since they give results in good agreement with measured values. A further study of this part of the subject is being undertaken.

Determination of Constants

The formulae developed in the previous section for the calculation of the sound articulation were:

$$d_i = \sum \frac{k_l}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

$$b = \Sigma\, p\, \Delta\, b$$

The following constants have, therefore, to be determined: p, Δ b, l, c_l, and k_l.

In his book *Speech and Hearing*, Fletcher gives curves which show the variation of articulation for the different sounds when the cut-off frequency of his high quality circuit is changed. Two curves are given for each sound, one curve corresponding to the case when all frequencies from the given frequency to infinity are passed, and the other curve corresponding to the case when all frequencies from zero up to the given frequency are passed.

The high quality circuit was constructed so as to pass all speech components in the pass range without distortion, and to suppress entirely all components outside the pass range.

It will be seen that each pair of curves cross, or would cross if carried far enough, at a certain frequency. This crossing frequency is different for different sounds. The articulation corresponding to this crossing frequency is the value obtained either by passing all components from the crossing frequency to infinity, or by passing all components from zero to the crossing frequency. It follows that the value of β of the band articulation for all components from zero to the crossing frequency will be the same as the value of β for all components from the crossing frequency to infinity.

But the probability of receiving a band correctly when all frequencies are passed is unity in the ideal case. Hence: the value of β for either of the regions, zero to the crossing frequency, or crossing frequency to infinity, must be 0.5 since $\beta = \Sigma\, \Delta\, \beta$.

If d_i^1 is the articulation corresponding to the crossing frequency, then we can write the expression

$$d_i^1 = \frac{1}{1+c_l\ (2^l-1)}$$

This expression contains two unknowns, c_l and l. It would, of course, be possible to evaluate these two unknowns if we knew some other corresponding values of d and β. A second pair of values could be obtained, for instance, by dividing up the frequency range zero to the crossing frequency in such a way that the articulation for the range zero to the new frequency was the same as that for the range from the new frequency to the crossing frequency. We should then know that the value of β for either of these sub-ranges would be 0.25.

Since, however, no information of this nature is available, it is necessary to determine both l and c_l from the one relation; and fortunately this can be done.

It is found that c_l does not vary greatly for different values of l. It follows, therefore, from the expression

$$d_i^1 = \frac{1}{1+c_l\ (2^l-1)}$$

that the greater the value of l the smaller will be the value of d_i^1. Those sounds having the largest values of d_i^1 will, therefore, be one band sounds; the next largest will be two bands sounds, and so on. From an examination of various published oscillograms, and analyses of speech sounds, it is possible to determine fairly definitely how many bands there are in some of the sounds, and this information, together with the values of d_i^1 enables us to determine values of l for all the sounds. It is possible that in some instances errors may have occurred; but, owing to lack of sufficient data, it is impossible at the moment to determine the values in any more exact manner. It is probable, however, that the effect on the final result will be small due to any errors that may have occurred in this way. As soon as further data are available, these values can be checked.

Having obtained a value for l in this way, the value of c_l for each sound can be determined directly from the expression

$$d_i^l = \frac{1}{1+c_l\,(2^l-1)}$$

The value of k_l, the fraction of the total number of sounds which has l bands, follows at once from the evaluation of l for the different sounds.

Finally, having determined the values of k_l, c_l, and l, the relation between d_i^l and b can be evaluated from the expression

$$d_i = \sum \frac{k_l}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

A curve for this expression has been worked out and is given in Figure 1.

In order to determine the value of Δ b, which is the average probability of receiving a characteristic band correctly when a small frequency region f_1 to f_2 only is passed to the listener, use is made of the curve given in Figure 136 of *Speech and Hearing*. This curve gives the average syllable articulation for the high quality circuit for different cut-off frequencies. As was pointed out in a previous paper, (12) and as Fletcher himself points out, (13) the relation between sound and syllable articulation for his lists is given by the expression

$$s = 0.2\ d^2 + 0.8\ d^3$$

Hence, by using this expression and the curve between d_i and b just obtained, it is possible to obtain from Fletcher's syllable articulation against cut-off curves, corresponding curves of b against cut off.

Now, since $b = \Sigma\ \Delta\ b$, we can obtain the value of Δ b for any frequency region f_1 to f_2 by determining values of b corresponding to f_1 and f_2 from either the low pass or high pass curves, and subtracting one from the other. If the theory developed here is correct, the corresponding values of Δ b, determined from the two curves, high pass and low pass, should be the same. Actually this is the case for frequencies from O up to 2500 periods. Above 2500 periods the frequency regions contribute less to articulation when frequencies from O to 1500 periods are present than they do when these latter frequencies are absent. This is due to the frequency spectra of the sounds such as S and Z. Figure 9 illustrates the frequency spectra for S and SH. It will be clear from this that the ear is in the habit of associating the SH sound with two bands; one from 500 to 2000, and one from 2000 to 4000. The sound S is associated with three bands, the first two being approximately the same as for SH, while the third is from 4000 to 6000.

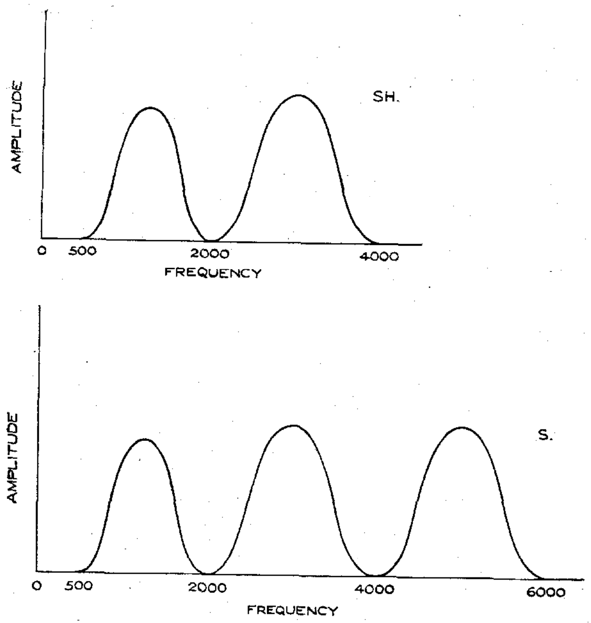

Figure 9

When frequencies from O to 2000 only are passed, the two sounds have very nearly the same spectra, but neither is the one usually presented to the ear. The listener, therefore, will not know whether a given sound is S or SH, but each will seem equally likely to him. He is thus likely to guess the sound as S 50% of the time, and as SH the other 50%.

When the range 2000 to 4000 is passed as well as the range O to 2000, the state of affairs is very different. Now the listener is receiving the whole spectrum for SH so that the articulation for this becomes 100%. When S is called, however, the listener receives very nearly the same spectrum as he is in the habit of associating with SH. Hence, for quite a large number of times he will mistake S for SH, so that the articulation of S will fall.

Finally, when the range 4000 to 6000 is passed as well as the other two, the listener receives the full spectrum for both S and SH.

When the region O to 2000 is absent, and only the region 2000 to 4000 is passed, the spectra for S and SH are the same, but neither are what the listener is used to receiving. The effect of the region 2000 to 4000 is now approximately the same for both sounds.

Hence, the value of the region 2000 to 4000, from the point of view of articulation, will depend for certain sounds on whether the region 500 to 2000 is present or not. If the latter is present, then the region 2000 to 4000, instead of helping articulation, actually hinders it. A similar state of affairs exists for certain other pairs of sounds.

Since for all practical circuits the region 500 to 2000 is present, it is the values of $\dot{\Delta}$ b determined from the low pass curve that we should take. A curve giving values of $\dot{\Delta}$ b for frequency bands of 100 periods is given in Figure 10, for this case. For certain exceptional cases where the region 500 to 2000 is wholly or partially suppressed, it is necessary to take different values for Δ b in the region 2000 to 4000, but, since this so seldom occurs, it has not been necessary to go into the question more fully at the present time.

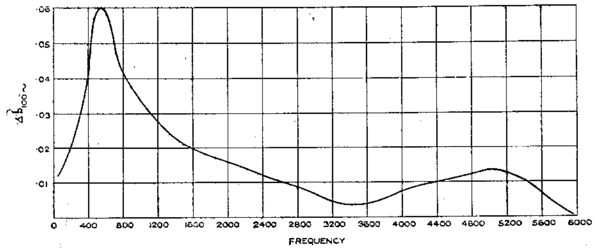

Figure 10

There only remains to be determined the value of p. If the speech components in a certain range f_1 to f_2 are passed from the speaker to the listener without distortion, but with a certain uniform attenuation, then, if a very large number of speakers take it in turn to talk to a very large number of listeners, p is the fraction of the total number of conversations in which the region f_1 to f_2 reaches the listener at such a level to be above threshold. It is, therefore, the average probability that the region f_1 to f_2 will reach the listener above threshold, when the given loss is introduced in the region. Its value can, therefore, be obtained by determining for the given range f_1 to f_2 the probability that a speaker will have a mean speech level a given amount above or below the average of all speakers, the probability that a speech sound will have a level a given amount above or below the average for all sounds, and the probability that a listener's threshold will be a given amount above or below the average for all listeners, and then combining the three probability frequency curves.

Values for the variation from speaker to speaker were obtained from a curve published by Fletcher(5). Values of the variation from sound to sound were obtained from the figures published by Sacia and Beck(9), on the assumption that the variations for the different frequency regions are the same as the variations of peak power. The variations of threshold from listener to listener were actually measured, since no data appeared to have been published.

The combined result of these three curves is given in Figure 5.

Apart from the constants which have now been evaluated, there still remains to be determined the speech level-threshold curve shown in Figure 4. This curve gives at each frequency the average level of speech components above threshold for initial speech intensity. It should be noted that we are only concerned here with those frequency components of the sounds which actually serve to distinguish one sound from another. The average level of these components for any frequency region is not necessarily the same as the average energy level for the same regions, because a sound may have quite a large amount of energy in some frequency region without this region contributing in any way to the articulation. It is not sufficient, therefore, to use the average energy spectrum for speech for determining the speech level-threshold curve, and it is necessary to arrive at the desired result by a rather roundabout method.

If the mean frequency and mean level above threshold could be obtained for each of the characteristic bands of speech, the speech level-threshold could be obtained by plotting points on frequency-level axes and drawing a mean curve through the points. This has been done, and the resulting curve is given in Figure 4. The method of obtaining the mean frequency and level for each characteristic band is by means of two sets of curves published by Fletcher(13). The first, from which the mean frequency is obtained, is the set of curves giving articulation against cut-off frequency for the different sounds when transmitted over the high quality circuit.

From the relation

$$d_l = \frac{1}{1+c_l\left[\frac{1}{\beta^l}-1\right]}$$

a series of curves can be constructed from the articulation cut-off curves of Fletcher, giving β against cut-off frequency. For each sound there will be two curves corresponding to the high pass and low pass circuits.

If a one band sound is taken and the characteristic band is divided into two parts by a frequency f so that the value of β for each part is equal, i.e., $\beta = 0.5$, then the frequency f can be considered as the mean frequency of the band. Hence for one band sounds the mean frequency is taken as that frequency corresponding to a value of β of 0.5 on the curves just constructed.

For a two band sound the mean frequency of the first band is that frequency corresponding to a value of β of 0.25 on the low pass curve or 0.75 on the high pass curve. Similarly, the mean frequency of the second band corresponds to a value of β of 0.75 on the low pass curve or 0.25 on the high pass curve.

In a similar way the mean frequencies for a three band sound correspond to values of β of 0.166, 0.5 and 0.883, and so on for other numbers of bands.

The second set of curves, from which the mean levels of the different bands are determined, is the set giving the articulation against intensity level for each sound. As before, these curves are transformed into a corresponding set of curves giving β against intensity level.

For a one band sound the mean level is that corresponding to a value of β of 0.5.

For a two band sound, if the levels of the two bands are such that when the intensity level has been dropped so as to cut one band out entirely the whole of the other still remains above threshold, the mean levels correspond to values of β of 0.25 and 0.75, respectively.

If the two bands overlap as regards level, the above rules do not apply, and a different method must be used. It has been found that for one band sounds the shape of the curve of β against intensity level is approximately the same whatever the mean frequency of the band. In fact, this curve is merely the same curve as that previously given in Figure 5, since one curve gives the probability that a band will be received above threshold while the other gives the proportion of cases in which the components in a given frequency range will reach the listener at a level above threshold.

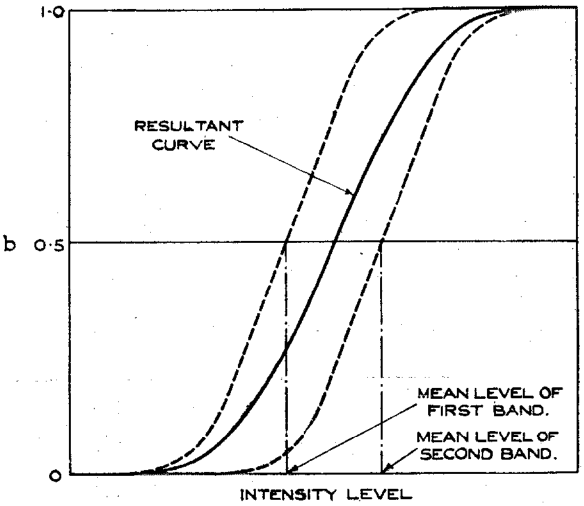

Figure 11

For a two band sound the curve of β against intensity level will be obtained by combining two of the curves for one band sounds, the two curves being placed so that the value of β of 0.5 in each case occurs at the mean level for the band. An example is shown in Figure 11. By trial and error it is possible to find for each of the two band sounds, the position of the two component curves such that the resultant curve fits the particular curve of β against level for the sound. The levels of the two bands of the sound are the same as the levels corresponding to the two component curves.

For sounds having a greater number of bands the same principle can be applied but with greater difficulty, of course.

In this way the mean frequency and mean level can be determined for each band in a sound, but, since the frequencies and levels are determined separately, there is no means of telling which particular level belongs to a particular frequency in the case of a multi-band sound. This difficulty was overcome partly by reference to oscillograms of the various sounds, and partly by the use of a curve giving the mean level of speech energy above threshold. This curve was obtained by combining the mean threshold curve and energy frequency spectrum of average speech given by Fletcher in his book, *Speech and Hearing*. This curve so obtained is not necessarily exactly the same as the curve giving the mean level above threshold of the characteristic bands of speech. It is, however, a sufficiently close approximation to it to enable us to allot the different levels to the different frequencies in this case.

LIST OF SOUNDS AND KEY WORDS

SOUND	KEY WORD	SOUND	KEY WORD
$\bar{\text{E}}$	ME	H	HE
E	GET	J	JUST
AH	PART	K	KICK
$\bar{\text{I}}$	MY	L	LET
I	IN	M	ME
$\bar{\text{A}}$	PAY	N	NO
A	AT	P	UP
$\bar{\text{O}}$	NO	R	RED
$\overline{\text{OO}}$	TOO	S	SO
OO	GOOD	T	IT
U	MUCH	V	GIVE
OW	HOW	W	WIN
AW	LAW	Y	YES
ER	HER	Z	PRIZE
B	BY	CH	WHICH
D	DO	SH	SHE
F	IF	TH	THAT
G	GET	EG	RING

In order to reduce the time required to calculate the articulation for a given circuit, values of $p\,\Delta b$ have been worked out for each 100-period frequency region from O to 6000 periods and for different values of overall attenuation. These values have been tabulated and a small section of the whole table is given below. This section is given merely to indicate the way in which the table is drawn up. The values in it are based only on the approximate determination of the constants, so that it was considered desirable not to give the complete table until the more exact evaluation of the constants has been completed.

The way in which the values of this table were obtained can be seen from Figure 6. Consider the frequency region f_1 to f_2 and let it be required to determine the value of $p\,\Delta b$ for this region for an overall attenuation of C decibels. The average level above threshold A of speech components in the region f_1 to f_2 is known from the speech level-threshold curve, curve No. 1, Figure 6. Hence the value $B = A - C$ is obtained. From the curve of Figure 5 we know that if the speech components are B decibels below the mean curve, the value of p has a certain value. From the curve of Figure 10 we also know the value of Δb for the region f_1 to f_2. The value of p is multiplied by the value of Δb and the value is inserted in the table at the point corresponding to the frequency region f_1 to f_2 and the attenuation C.

Comparison of Calculated and Measured Results

In order to show with what accuracy the articulation can be calculated by the method described in this paper, a number of examples are given for which the articulation has been calculated and for which actual measured results are available. In judging these results, it should be remembered that the constants used in the calculated values of articulation are only approximate, so that when the final evaluation of these constants is made the agreement between measured and calculated results should be even better than it is now.

The examples which have been worked out here have been taken from Fletcher's book, *Speech and Hearing*, and the values he gives are the values of syllable articulation actually measured by his testing crews. The values of ideal sound articulation calculated by the method described

MEAN FREQUENCY AND LEVEL OF ARTICULATION BANDS

Sound.	No. of Bands.	Freq.	Level.	Freq.	Level.	Freq.	Level.	Freq.	Level.	Freq.	Level.
Ē	1	1575	90								
L	1	1000	80								
NG	1	1725	82								
Y	1	2125	84								
Ī	1	1425	87								
R	2	1250	85	2000	85						
I	2	600	92	2000	87						
Ā	2	500	93	1900	98						
D	2	1375	76	3125	71						
CW	2	900	98	1375	93						
$\overline{\text{OO}}$	2	650	85	1900	85						
SH	2	1720	86	2700	86						
Ō	2	700	81	1225	101						
W	22	825	81	1125	86						
J	2	1050	82	2900	82						
A	2	875	93	2100	83						
H	2	1100	80	1575	50						
N	2	1000	85	3200	65						
AW	2	875	86	1375	106						
CH	2	1575	92	3250	62						
M	2	775	72	2000	67						
B	2	500	79	2375	59						
K	2	1375	78	3125	58						
G	2	1360	82	2625	62						
V	2	750	66	3000	46						
AH	2	790	92	2050	92						
T	2	1875	78	4500	68						
Z	2	1250	70	4250	45						
ER	3	750	98	1625	98	2400	93				
P	3	1075	85	1925	65	2750	50				
E	3	650	85	1000	85	1750	85				
F	3	1000	96	2250	66	4200	56				
U	3	625	84	1250	104	2125	78				
S	3	1350	60	2700	60	5500	60				
OO	4	250	69	800	105	1700	95	3000	79		
TH	5	200	20	625	110	1875	100	3800	70	6600	40

VALUES OF $p \Delta b$.

FREQUENCY	OVERALL ATTENUATION (DECIBELS)							
	52–54	54–56	56–58	58–60	60–62	62–64	64–66	66–68
1200–1300	0206	0259	0258	0257	0255	0252	0249	0245
1300–1400	0240	0239	0238	0236	0234	0231	0228	0222
1400–1500	0220	0219	0218	0217	0215	0212	0209	0204
1500–1600	0199	0199	0198	0196	0194	0191	0188	0184
1600–1700	0189	0188	0187	0185	0183	0180	0176	0172
1700–1800	0178	0177	0175	0173	0171	0167	0164	0160
1800–1900	0168	0167	0165	0162	0160	0156	0153	0149
1900–2000	0157	0155	0153	0151	0147	0144	0140	0136
2000–2100	0150	0148	0146	0143	0140	0135	0131	0126
2100–2200	0140	0137	0134	0131	0128	0125	0121	0115
2200–2300	0129	0126	0123	0120	0116	0113	0107	0102
2300–2400	0118	0115	0113	0110	0104	0102	0098	0092
2400–2500	0107	0105	0102	0099	0097	0092	0088	0082
2500–2600	0096	0094	0090	0088	0084	0080	0075	0069
2600–2700	0090	0088	0085	0082	0078	0073	0068	0063
2700–2800	0079	0076	0074	0070	0066	0061	0057	0052

in this paper have, therefore, been converted to the corresponding ideal syllable articulation for comparison with Fletcher's results. The calculated values of syllable articulation will, of course, always be a little higher than the measured values because the calculated values are the ideal values and the measured are not. In most of Fletcher's results the measured values are very near the ideal values because his testing crews were so highly trained as to approximate very nearly to the ideal crew. In some cases sufficient information was available to enable the constant Z of Fletcher's crew to be determined; in these cases the actual measured results have been corrected to the corresponding ideal syllable articulation, using the method given in the appendix.

The cases worked out are as follows:

(1) The articulation for the high quality circuit at different intensity levels. The results are given in Figure 12. The measured curve is Fletcher's mean curve and the points are values of ideal syllable articulation obtained by correcting one set of his measured values using a crew constant of Z=.95. The crew constant of 0.95 was obtained by noting the value of articulation obtained by the crew at an intensity level of 75 decibels, since the value of b for this level is 0.5.

The measured curve, as would be expected, is a little lower than the calculated, but the corrected points lie very well on the calculated curve.

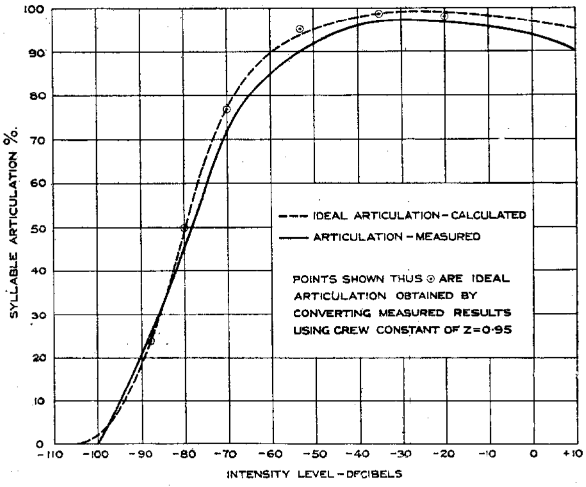

Figure 12

(2) The high quality circuit with a resonant circuit tuned to 1100 periods per second and a damping of 450 bels per second.

The calculated value of ideal syllable articulation was 94% and the measured value was 92%.

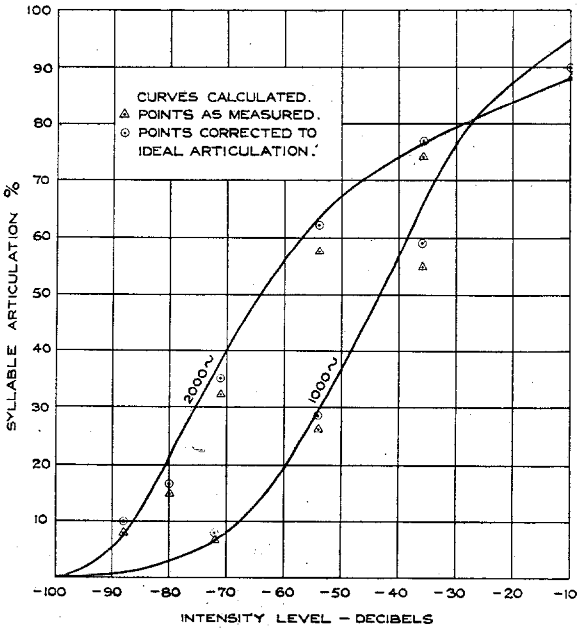

Figure 13

(3) The same as above but with the resonant circuit having a damping of 35 bels per second.

The calculated value of ideal syllable articulation was 83.5% and the measured value was 80%.

(4) The high quality circuit with added 1000 period and 2000 period noise. The results are given in Figure 13.

The upper points were obtained by correcting the measured results with a crew constant of Z=0.95. The lower points are the actual measured values.

The corrected figures are in good agreement with the calculated curves.

On the whole the measured and calculated results are in good agreement; where the actual crew constant could be obtained the agreement is still closer.

In the case of the upper parts of the curves given in Figures 12 and 13, and in the case of the values given for cases (2) and (3) the allowance for overloading had to be made. It appears to give reasonable results.

Conclusions

As pointed out at the beginning of this paper, the evaluation of the constants is approximate only, since it was carried out with the aid of such data as had been published, and was done in order to determine, before going more fully into the subject, whether the theory was capable of giving results in agreement with practice. This point should be kept in mind when considering the results since it explains differences which occur in some instances between calculated and measured results. In spite of the approximate values of the constants, the agreement between the calculated articulation and the measured values is, in most cases, quite good and within the limits of experimental error. There are, admittedly, still many points which require further investigation, and it is hoped in the course of the next year to devote time to the study of these points in addition to a more accurate evaluation of the constants.

In conclusion, it can be said that, except for minor modifications, the theory can be taken as representing the actual conditions with sufficient accuracy to enable it to be applied to the calculation of articulation in practical cases. Further, the tabular form in which the results have been presented makes it possible to calculate the articulation for a given circuit in a very short space of time. The use of the Ideal Sound Articulation as a criterion of the quality of speech obtainable over a circuit deserves some mention. This quantity is independent of errors due to the testing crew and is, therefore, a true measure of the characteristics of the circuit.

This fact, together with the easy method described here for converting the articulation as measured by a given crew to the corresponding ideal sound articulation, makes the Ideal Sound Articulation particularly useful as a measure of the performance of a telephone circuit. An added advantage is the fact that syllable articulation, word articulation, intelligibility and time efficiency can all be calculated from the Ideal Sound Articulation.

Before concluding this paper, the author would like to express his appreciation of the many papers written by members of the Bell Laboratories of America, to which constant reference has been made throughout this work. It is no exaggeration to say that without the results published in these papers, this preliminary demonstration of the accuracy of the theory could not have been made at the present time. In addition, thanks are due to those members of the staff of the Development and Research Laboratories of the International Telephone and Telegraph Corporation who have helped in the work and the preparation of this paper.

LIST OF SYMBOLS

b = Average band articulation for all sounds.
β = The band articulation for a given sound.
Δb = The value of b for a small frequency range f_1 to f_2.
l = Number of characteristic bands in a sound.
c_l = Constant depending on the total number of groups of l characteristic bands and the number of sounds having l characteristic bands.
k_l = Proportion of sounds in speech having l characteristic bands.
d_l = Sound articulation for sounds with l characteristic bands.
d_i = Average Ideal Sound Articulation.
d_i^1 = Value of d_i at frequency where high pass and low pass articulation-frequency curves cross.
d = Average sound articulation obtained by a given testing crew.
P = Proportion of speech components in a given range which are above threshold for a given level of speech.
Z = Crew Constant.
= Average probability that a given crew will receive a characteristic band correctly over a circuit for which $b=1$.

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APPENDIX

Calibration of Articulation Testing Crew

The whole of this work has been based on the ideal sound articulation which is, by definition, the value that would be obtained by an ideal testing crew. This value is used because it is independent of the crew and is, therefore, a true measure of the quality of speech obtainable over a circuit.

The actual value of articulation obtained by any given crew will fall short of the ideal value due to errors introduced by the crew. These errors will be of two kinds, errors due to faulty pronunciation of the caller, and errors due to inattention and other causes affecting the listener. Some method of determining the ideal sound articulation from a value of actual articulation measured by a given crew is therefore necessary.

In a previous paper the following expression was given

$$D = D_i \times D_e$$

where D is the percentage sound articulation, D_i is the ideal sound articulation, D_e is a constant for a given testing crew and is the value of articulation that crew would obtain over an ideal circuit.

Actually, tests have shown that this relation does not hold in practice and a further study of the theory indicates that it could not be expected to.

The form of this expression is correct, but instead of using the sound articulation it is necessary to use b, the probability of receiving a characteristic band correctly. This is obviously the case since it is the characteristic bands of speech that are either recognised or not recognised by the listener. The relation between ideal and actual sound articulation will, of course, depend on the relation.

$$d_l = \frac{1}{1 + c_l \left(\frac{1}{\beta_l} - 1 \right)}$$

and will not be of the simple form $D = D_i \times D_e$.

The expression for the sound articulation as measured by a given crew then becomes

$$d = \sum \frac{k_l}{1 + c_l \left[\frac{1}{Z^l \, b^l} - 1 \right]}$$

where Z is a constant for a given crew and is the average probability that the crew will receive a characteristic band correctly over an ideal circuit.

This expression has been checked by actual tests and has been found to be correct within the limit of the experimental error of the test results.

The value of Z for the ideal crew is therefore unity, so that the expression for the ideal sound articulation is, as before,

$$d_i = \sum \frac{k_l}{1 + c_l \left[\frac{1}{b_l} - 1 \right]}$$

In order to determine the value of Z for a given crew, it is sufficient to obtain a measured value of articulation with the crew on a circuit for which b is known. It is preferable to use a circuit having a value of b approximating to that obtained on ordinary telephone circuits, i.e., a value of about 0.5. A circuit having a value of b of 0.5 can, of course, be constructed by using a high quality circuit in conjunction with a filter designed to cut off all frequencies above 1550 periods per second.

The curve given in Figure 4 gives values for d_i and b for the expression

$$d_i = \sum \frac{k_l}{1 + c_l \left[\frac{1}{b^l} - 1 \right]}$$

The same curve can, therefore, be used to give the relation between d and Zb in the expression

$$d = \sum \frac{k_l}{1 + c_l \left[\frac{1}{Z^l b^l} - 1 \right]}$$

In order to determine Z for a given crew the procedure is as follows: Measure the articulation with the given crew for the circuit where b is known; let this value be d^1. From the curve the corresponding value of Zb is obtained and, since b is known, the value of Z is obtained directly. Then if a value of articulation of d is measured on a circuit for which the ideal sound articulation is required, the value of Zb corresponding to d is obtained from the curve. Since Z is known, the value of b can be calculated and, using the curve once more, the corresponding value of d_i is obtained.

The Training of Local Staff in Ceylon for Communication Engineering Works

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NOT the least of the difficulties which the Communication Engineer in the tropics has to face is the formation and adequate training of a staff capable of installing and maintaining, in an efficient manner, any or all of the diverse types of plant which the rapid developments in the science of communications now demand, and it has been suggested that a short description of what is being done in Ceylon to achieve this end may be useful to other Administrations similarly placed.

First of all, a few words about the country and its people. Ceylon is regarded as the premier Crown Colony of the British Empire, and is situated near the southern point of India. It does not, however, as many people imagine, form part of British India, either politically or otherwise, notwithstanding the poetical description sometimes given to it as "the pearl on the brow of India." It has an area of over 25,000 square miles, about half the size of England, the most northerly point being only 9° 50′ north of the Equator, while the southern point reaches to within 5° 55′ of the Circle. Its population is approximately 5½ millions, consisting of Sinhalese, Tamils, Moors, Burghers, Eurasians, Malays, and Europeans, the Sinhalese largely preponderating in numbers.

The centre of the Island possesses an extensive mountainous region reaching an altitude of 8,300 feet, and in consequence of this, the climatic conditions met with are very varied. There are two monsoons, viz., the southwest, blowing from May to September, and the northeast, from November to February. These generally bring considerable rain, which is deposited on the windward side of the central hills, some portions of these receiving so much as 200-250 inches per annum, while the southwest maritime districts average 75-150 inches per annum.

Over the greater portion of the low country the percentage humidity exceeds 90% during the

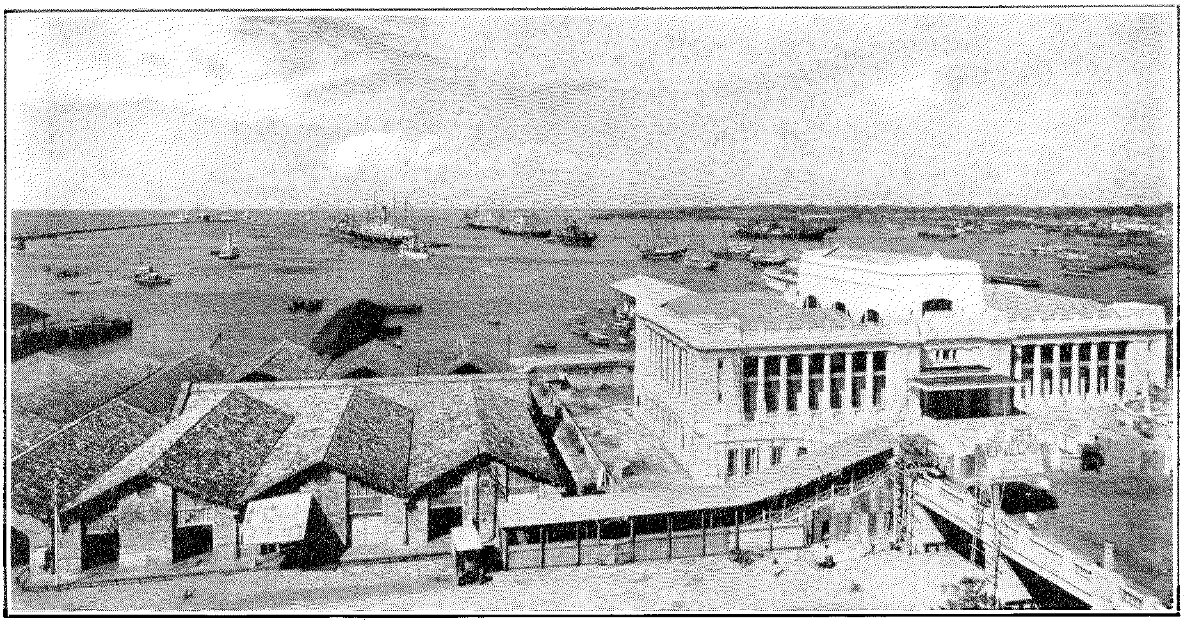

Figure 1—Colombo Harbour. Known to Many as the "Clapham Junction of the East."

greater part of the year, with mean shade temperatures varying from about 78° to 85° Fahrenheit. At certain up-country stations the temperature frequently drops to freezing point during the nights in the early months of the year, as much as 12° of frost having been recorded quite recently in some places. The high percentage humidity and temperature in the low country add considerably to the difficulties of maintaining many types of telephone plant as compared with more temperate regions.

The central and southwestern districts are highly developed agriculturally, the centre of the Island being devoted almost exclusively to the cultivation of tea and rubber, while in the coastal districts cocoanuts largely predominate.

The value of these three principal exports for the year 1927, in Rupees, amounted to:

Tea	Rs. 213,691,876
Rubber	Rs. 119,174,347
Cocoanut Products. .	Rs. 77,048,541

In addition to the above, Ceylon grows Cocoa of the finest quality obtainable, and exports it to the value of nearly three million rupees per annum, while other important crops are Cinnamon, Citronella Oil, Tobacco, Cardamoms, and Areca Nuts. Plumbago is the principal mineral export; and Ceylon gem stones, particularly sapphires, are world famous.

There are 900 miles of railways operated by the State, and an excellent system of roads covers the Island. As a consequence of the latter, motor road transport has developed enormously during the past five years.

The capital of the country is Colombo, which is the headquarters of the Administration, and the centre of mercantile activity. The population is estimated at approximately 300,000. It possesses a very fine artificial harbour that covers 643 acres, of which 400 acres have a depth of over 30 feet. It is equipped with electric and steam cranes, up-to-date coaling jetties, and a large oil depot.

Trincomalee Harbour, on the east coast, is noted as one of the finest natural harbours in the world.

A start has been made with the construction of a hydro-electric power scheme estimated to develop 15,000 kw. of electric power, distributed by 88,000 volt main transmission lines.

The total revenue and expenditure of the Colony for the financial years 1926–27 amounted to Rs. 129,358,916 and Rs. 121,046,299, respectively.

It will be gathered from the above brief description that Ceylon is one of the most progressive of eastern countries; and the Telephone and Telegraph Department does not lag behind in this respect. Although the telegraph system has been under the control of the Ceylon Government for many years, the telephone system was only taken over in 1910. The Great War and subsequent trade depression prevented the service being seriously developed until 1922. Since then, however, much has been done to make up leeway, and the demand for further facilities shows no signs of abating. What has been done during the past six years may, in fact, be regarded as only touching the fringe of future development if the Colony continues to prosper.

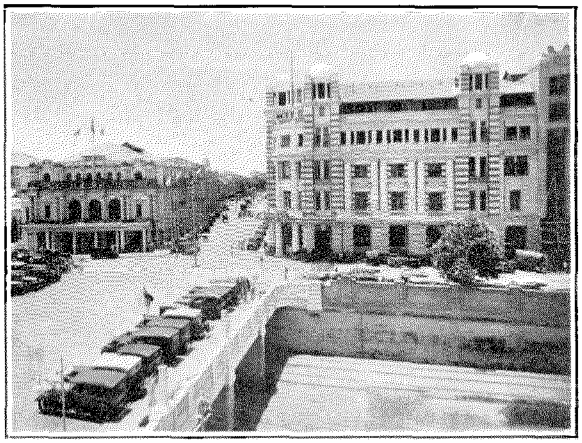

Figure 2—York Street, Colombo, with Grand Oriental Hotel on right.

Seven years ago, the telephone system extended only to a limited number of the principal towns in the country, the exchange apparatus consisting of simple magneto switchboards, the prevailing impression then being that more modern types of apparatus could not satisfactorily be maintained, owing to the severe climatic conditions which prevail. Systematic tests, however, quickly dispelled this illusion, and there are now being satisfactorily worked several C. B. and small automatic exchanges, in addition to many C. B. private branch exchanges, while schemes

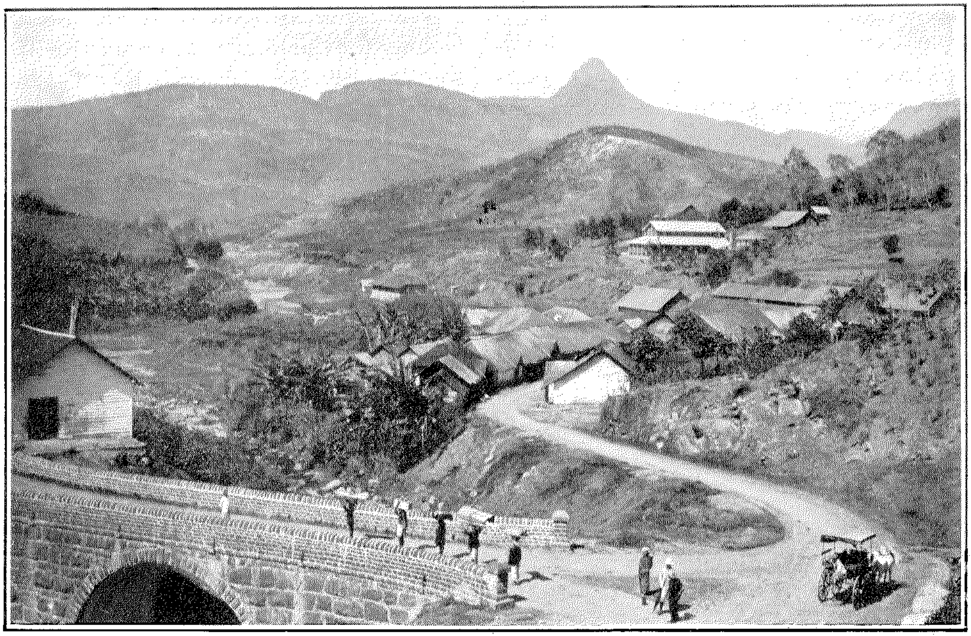

Figure 3—Ceylon. Typical Tea Country. Adam's Peak (7,400 ft.) in background.

are in hand to modernise the remainder of the plant. Plans have been approved for the conversion of the Colombo exchange service to automatic, and a start will be made with the first of the exchanges in 1930. Simultaneously, the telephone system has been extended to include all but three of the principal towns in the country, and it is expected that these will be connected within the next two years.

The underground cable system has been greatly increased and now includes a 27 pair loaded trunk cable, together with a similar unloaded main telegraph cable, each 30 miles in length, recently installed by Standard Telephones & Cables, Ltd., forming part of a scheme which, when completed, will extend to Galle—72 miles distant from Colombo.

Telephone repeaters have been installed at Kandy, the principal town in the centre of the Island, and a single channel carrier circuit will be fitted next year to work between two important towns.

Considerable attention has been given to the development of rural exchanges, particularly to the possibilities of working these automatically or semi-automatically with a view to giving the subscribers connected to them a twenty-four hour service, and several rural type automatic and semi-automatic switchboards have been ordered for schemes at present under construction. In an agricultural country like Ceylon, there is great scope for the development of such services.

The telegraph system has simultaneously been considerably modernised. Teleprinters of the start-stop type have been fitted at several of the more important offices, and their use is being rapidly extended. An extensive system of these instruments is at present being installed for the Police Department.

Ceylon was early in the field in the matter of broadcasting. In order to meet the public demand, the Government agreed in 1924 to introduce a limited broadcasting service. A small improvised transmitter was first used for the purpose, followed, in 1925, by a 1.75 kw. transmitter, designed and built locally by the writer, using Standard Telephones & Cables' microphones and amplifiers, which have rendered good service during this period. This was the first regularly operated and successful broadcasting service in the East.

The Telephone and Telegraph Department is also responsible for all the electrical safety plant and communications on the Railway System, and equally important developments have been undertaken in these during the past five years, including a network of train control telephones, supplied by Standard Telephones & Cables, Ltd., an extensive electrical flood alarm scheme protecting 200 miles of track, a great extension of track circuiting, etc., while schemes are being prepared for the immediate introduction of colour light signalling, electrically worked points and signals, and other modern developments in railway safety and signalling practice.

All these matters are, of course, the commonplaces of the Communication Engineer's profession, and the writer only refers to them in order to demonstrate the importance of the proper training of the personnel who have to install and maintain this plant.

When it is remembered that, with the exception of the Headquarters Engineers, the experience of the remainder of the staff was limited to the simplest form of telephone and telegraph plant, and that this staff has had to be increased approximately 200% to cope with the developments, the need for systematic and intensive training of these will be manifest.

A school equipped with every type of apparatus to be handled, and officers fully competent to impart the necessary tuition, should be regarded as an essential part of every Administration, and will prove one of the best possible investments if organised on sound lines.

A start was made with such a school in Ceylon about five years ago, but owing to the lack of a suitable building, not much progress could be made until two years later.

Description of School

The school now consists of the following sections:

(a) Telephones and Telegraphs.
(b) Railway Signalling.
(c) Underground cable jointing and plumbing.
(d) Overhead line construction.
(e) Technical Laboratory.

It will perhaps be best to describe briefly the equipment of these sections before dealing with the instruction given therein.

(a) *Telephones and Telegraphs Section.* Two photographs, Figures 4 and 5, show the general layout. One half of the centre of the room (vide Figure 4) is fitted with apparatus tables which are used by the students for the dual purpose of taking notes during lectures, and for the layout and use of demonstration apparatus. A series of panels, some of which can be seen on the table in the foreground of Figure 4, are provided, on which certain portions of telephone apparatus are fitted, wired up in skeleton fashion, to assist the student to visualize most effectively the circuit wiring of different types of telephones, switchboards, cord circuits, etc. These panels are much more effective for the purpose than the usual paper diagrams, as they put before the beginner, in concrete form, the actual apparatus he will have to handle. The wiring is easily stripped, and the students are required, at frequent intervals, to rewire them from memory.

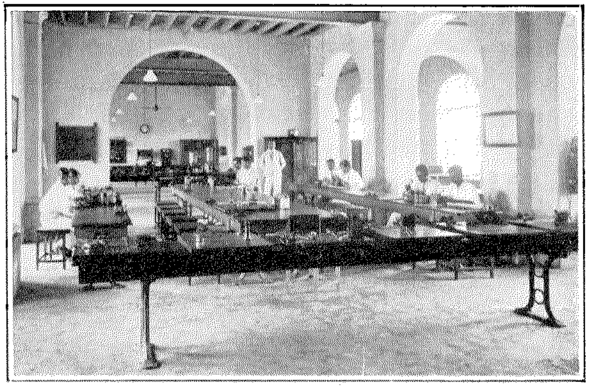

Figure 4—Telegraph Department Training School. General View of Telephone and Telegraph Section.

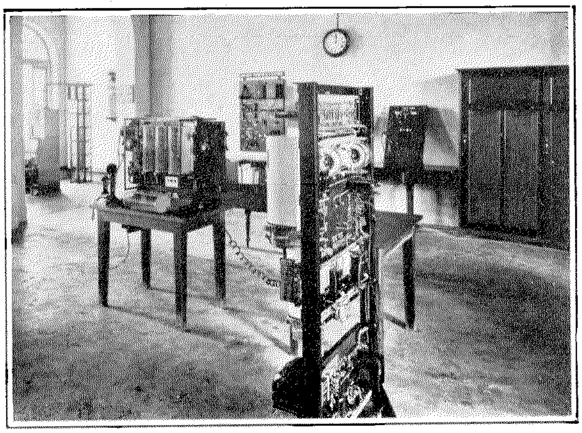

Figure 5—Telegraph Department Training School. Telephone and Telegraph Section. Automatic demonstration sets in foreground. Model office in rear at left.

A fairly complete set of the different types of telephones, switchboards, and auxiliary apparatus in actual use is provided. These are used for various demonstrations, and to put on faults for the student to locate and clear.

Three types of automatic demonstration sets have been fitted, two step-by-step and one relay type, and it is hoped shortly to add another of the rotary type. With these, the main principles of automatic working can be shown to the students, and correct methods of dialing and making adjustments can be taught. These auto sets can be seen in Figure 5.

One section of the room is fitted as a model small office, and is complete with switchboard, distributing frame, and telegraph instrument table, all wired in the standard approved methods.

Another section is devoted to a small power plant with secondary cells which are used for tuition purposes, and also to supply the necessary current for operating the apparatus in the school.

Correct methods of wiring the tagging switchboard jacks and cables are taught in one of the aisles of the main hall. Another aisle is devoted to telegraph apparatus, fitted with start-stop teleprinters, and Morse instruments for simplex, duplex, and quadruplex working.

(b) *Railway Signalling Section.* This section is equipped with a complete miniature railway, so arranged that every type of safety apparatus in use on the Ceylon Government Railways can be demonstrated.

A model track of 1¾" gauge and over 250 feet in length is fitted on trestle tables arranged along the sides of the room with a "run round" at each end. The track is divided into three double line sections, and four single line sections with seven stations.

These stations are arranged with crossovers, model signals and other equipment to represent actual working conditions, the double line stations being fitted for lock and block working and track circuiting, the actual full size apparatus being used, of course, for this purpose. Similarly, the single line stations are equipped with complete sets of tablet apparatus and other accessories. Model electrically driven trains are used to demonstrate the working of the various apparatus. The centre of the room is arranged for lecturing purposes. The general layout is illustrated in Figure 6. Figure 7 illustrates one of the stations.

(c) *Underground Cable Jointing and Plumbing Section.* For the purpose of training men in this class of work, a series of small square wooden benches have been provided. The tops of these benches are zinc covered, and are fitted with clamps at each end, which will grip tightly any size cable. The joints are made between each two adjacent tables, the distance between them being adjusted to suit the length of joint to be made. Scrap lengths of cable are, of course, used for training purposes. Between the spacing of adjacent tables are arranged zinc trays to catch the scrap copper and plumbers' metal. The usual tools for jointing and plumbing, with detectors and meggers for taking the ordinary conductivity and insulation tests, are provided. The general layout is indicated in Figure 8.

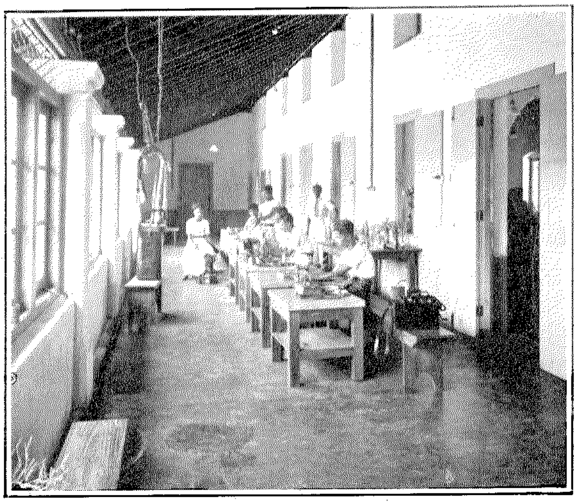

Figure 8—Telegraph Department Training School. Underground Cable Section.

(d) *Overhead Lines Section.* A series of model poles is erected in the open air outside the main building, on which can be demonstrated straight, twisted, and transposed methods of wiring and terminating. Some of the poles have been shortened, as shown in Figure 9, to enable the tutor easily to watch the men under training, and correct their mistakes. Full size model distributing poles with terminating underground cable, and also models of every type of insulator, joint, and method of terminating are also provided.

(e) *Technical Laboratory.* Although, strictly speaking, this is not regarded as part of the training school, it serves the dual purpose of providing for all the technical tests required in the Department, and for more advanced training in radio work, transmission measurements, and other experimental investigations which have to be carried out. It is housed in the same building as the other sections, and is equipped with, amongst other apparatus, the following:

A fairly complete set of apparatus for measurements at radio frequencies.
Cathode Ray Oscillograph.
Low Frequency and High Frequency Oscillators.
A. C. Bridges.
Transmission Measuring Sets.
Terminating Network.
Cross Talk Sets.
Precision Wheatstone Bridges, Standard Inductances, Capacities, etc.

Each of the sections is in charge of an officer carefully selected for his ability to impart a sound practical knowledge to the men under training, the whole being controlled by a senior officer who, needless to say, must be still more carefully selected, as the success of the school largely depends on him.

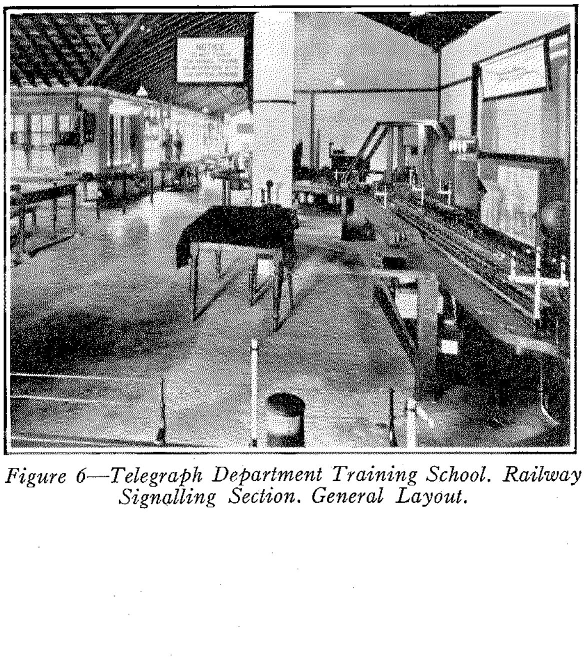

Figure 6—Telegraph Department Training School. Railway Signalling Section. General Layout.

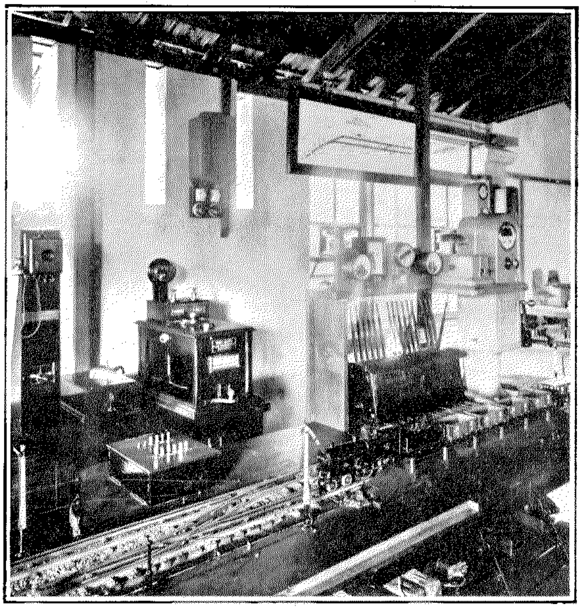

Figure 7—Telegraph Department Training School. Railway Signalling Section. Model station with tablet working on single line to left, and lock and block with double line to right. Note the model train standing at the station.

SCHEME OF TRAINING

The primary object of a school such as that here described is, of course, to produce officers capable of maintaining satisfactorily any or all of the types of plant referred to earlier in these notes, or who can take charge of small working parties for the construction and installation of such plant. They must be given a sufficient training in the theory and principles of operation to enable them to do so intelligently, but, above all, they must be thoroughly practical men who can, in turn, train the workmen under them.

The greatest care is taken in the first instance to select candidates of the right class with a sufficient basis of general education on which to build. Much more satisfactory results are obtained by selecting youths who have just left school than from ex-motor mechanics, or others who have received a smattering of training elsewhere. After the training has commenced, the process of weeding out unsuitable individuals is pursued ruthlessly, in order that those who are ultimately given permanent appointments represent the "survival of the fittest."

The standard of general education required in Ceylon for those candidates who are to be given the full course of training is that of the Cambridge Senior examination. They are entered as Overseers-in-training, and are given a preliminary course extending at present over ten months, four of which are absorbed in the Telephone and Telegraph Section, and two in the Railway Signalling Section.

If passed as satisfactory, they are then sent out on actual field work in company with more experienced officers.

It is intended, as soon as the pressure is relaxed, to extend this preliminary course to twelve months, and to bring in these men for further training at intervals, until they can be regarded as thoroughly trained.

The twelve months' course is allocated as follows:

1 month General Principles.
3 months Telephones.
1 month Telegraphs.
2 months Lines and Cables.
3 months Railway Signalling.
1 month Stores and Office Routine.
1 month Workshops.

Total 12 Months

During the past two years 118 candidates have passed through the full course, and the rejections have amounted to 18%. Seventy-six men of other grades have been given shorter courses.

For the grades of Inspectors and officers up to the rank of Assistant Engineer, a more comprehensive course of training is in force.

Candidates for these grades are selected from young men between the ages of 17 and 22 years. As regards general education, the Matriculation standard is preferred, but the Cambridge Senior standard is accepted if the candidate is otherwise satisfactory. In each case preference is given to those who have passed in Mathematics, Physics, Applied Mathematics and (or) Chemistry.

Selected candidates are required to undergo a five years' course of training before they become eligible for appointment as Inspectors.

This period is made up of two years at the Government Technical College, attending classes on Telephone and Telegraph Engineering, Radio Communication, and Electrical Engineering followed by three years' practical training as follows:

6 months Departmental Workshops.
3 months Telegraph Apparatus.
6 months Telephone Subscribers' Apparatus.
6 months Telephone Switchboards and Testing.
2 months Stores and Office Routine.
4 months Railway Signalling, etc.
6 months External Construction and Maintenance.
2 months Radio Engineering.
1 month Drawing Office.

Total 3 years.

The Technical School's curriculum is specially drawn up to meet the requirements of the Department, and a good deal of the actual lecturing is given by the Department's Engineers. Before commencing their practical training, the students are required to pass a preliminary examination. During the period of practical training, it is obligatory to attend evening classes on Building Construction, and to pass prescribed examinations in Telephony and Telegraphy.

This scheme has now been in operation seven years, and has been successful in producing a type of young officer in whose hands the future well-being of the services is assured.

Finally, a word about the training of Ceylonese for the grades of Headquarters' Engineers. It has been the policy of the Ceylon Government for many years to encourage the local staff to qualify for the higher posts in the technical departments, but, owing to limited facilities available for training, it was not practicable to make a serious start in the Telegraph Department until six years ago.

A scheme was then prepared to give a three years' comprehensive course of training in England to selected Celonese senior Inspectors. By the courtesy of the Postmaster General and Engineer-in-Chief of the British Post Office, it was arranged that two years should be spent in that Department, the third year being devoted to training in Railway Signalling and visits to Works. Each officer was required to pass the Associate Membership examination of the Institution of Electrical Engineers before his return. Several have sucessfully completed this training.

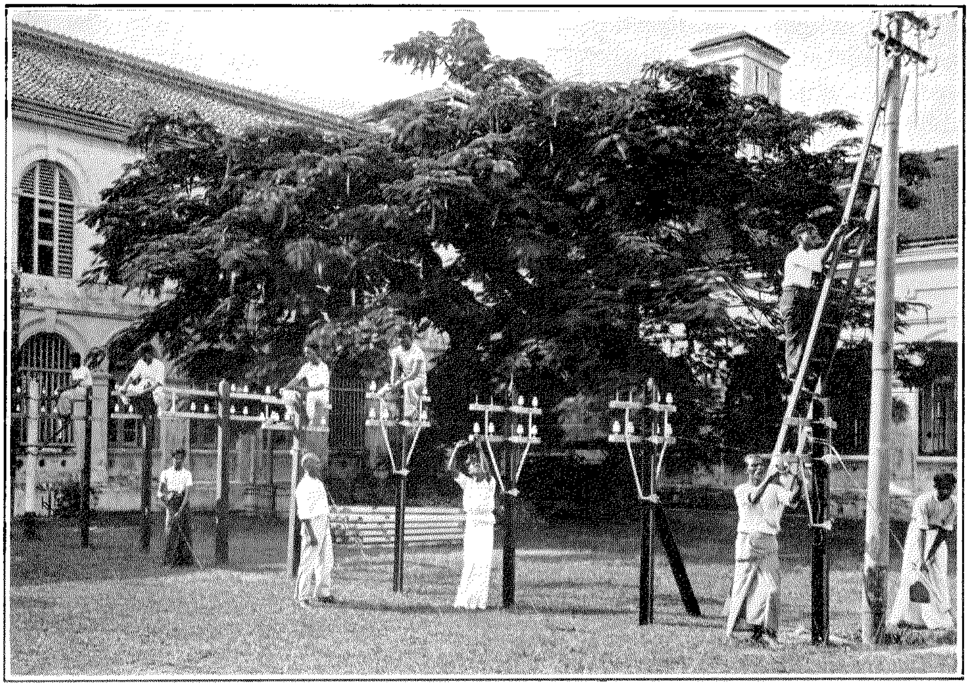

Figure 9—Telegraph Department Training School. Overhead Lines Section.

A further improvement on this arrangement has just been authorized. Scholarships tenable for 3½ years are to be awarded by Government to selected students of the Ceylon University College who have taken their Science degree. These students are to be sent for a two years' course in electrical and communication engineering at the London University, during which period they are required to obtain the Engineering degree of this Institution. This is to be followed by 1½ years' practical training in the British Post Office, and with approved manufacturing firms.

In giving this outline of the various training schemes now in operation in the Ceylon Telegraph Department, it is not suggested that they contain any original ideas. They may, however, serve as a useful indication of what can be done by other small Administrations in the matter of providing a thoroughly trained technical staff, and, as the whole of these schemes have been brought to maturity during the short period of seven years, there is no need to defer to the Greek Kalends the development of vital communication services, even in those countries where such development is still in the embryo stage, if the training of the local staff is taken in hand energetically and systematically.

APPENDIX

Synopsis of Training Courses

(a) *Telephone and Telegraph Section.*

General electrical theory. Meaning of terms. Practical units. Ohm's law. Theory of magnetism. Magnetic properties of iron and steel. Magnetic effects of a current and generation of currents by means of magnets. Direct and alternating currents. Induction and capacity.

Primary batteries. Description and explanation of Leclanche, "A. D." Edison (Caustic Soda) and dry cells. Practical maintenance of them and purposes used for. Testing voltage, Internal resistance and general condition. Connecting up cells in series and parallel.

Telephone apparatus. Description and elementary explanation of working of magnets and Central battery instruments, manual and automatic switchboards, and auxiliary apparatus. Practical handling, assembling, dismantling, and maintenance of all types of apparatus used by the Department. Testing and localising faults on apparatus and switchboards. Practical wiring and connecting up. Testing of circuits from main distributing frame. Jumpering. Switchboard wiring and cabling. Fault records, etc. Power Plant. Description of D.C. and A.C. motors and generators. Secondary batteries, description and explanation of different types. Specific gravity of acid. Practical maintenance, charging, and discharging Rectifiers.

Telegraph apparatus. Simplex, duplex and quadruplex working. Description and practical maintenance and adjustment of apparatus. C. B. working. Start-Stop machine telegraphs (teleprinters). Morse signalling and receiving.

Testing Apparatus. Theory and use of Wheatstone bridge, megger, Varley loop test. Testing by Voltmeter, etc.

(b) *Railway Signalling Section.*

General principles of Signalling and Safety Working. Double and single lines. Functions of different types of Signals and where placed. Points, trailing and facing. Principles of interlocking.

Double line working. Lock and Block. Procedure in working a train through a L & B section. Electrical circuits and mechanical locking. Practical assembly and adjustments of instruments. Maintenance and testing for faults.

Single line working. General explanation and system. Tablet working. Procedure in working a train through a single line section. Description of tablet instruments. Failures and how caused. Transference of tablets. Procedure in case a tablet is lost or damaged. Practical assembly and adjustments. Maintenance and testing for faults. Bank Staff working. Method of operating. Description of Staff box and electrical interlocking with tablet instrument. Auxiliary and special arrangements.

Track Circuiting. Functions. Description of different types of circuits and apparatus. Rail bonding and insulating. Applications to double and single line working. Control of signals and points. Illuminated track diagrams at stations. Maintenance routine.

Signal Repeaters. Description of repeaters for arm and light or arm only. Electrical circuits. Routine testing, adjusting and maintenance.

Flood Alarms. Functions. Description of apparatus fitted at controlling station, terminal station, and cooly lines. Electrical circuits. Testing and flood localisation by means of potentiometer. Routine when alarm is given and in resetting circuits. Fitting of flood traps. Adjustment and maintenance routine.

(c) *Underground Cable Section.*

The different classes and types of cable used. Care of cables and how they should be handled. Protection of cable ends. Earthenware ducts. C. I. and steel pipes, how they are laid. Jointing chambers and manholes. Dimensions and methods of construction in brick and concrete. Drawing in cable and use of winches and rope tackle. Method of opening cable. Numberings and Colour Scheme. Correct methods of testing and jointing, and special precautions to be observed in the Tropics. Head sleeves and plumbing of joints. Pressure testing. Desiccating. Preparation of cable distribution plugs and potheads. Terminating on distributing pole with enamel and cotton covered twin lead cable. Numbering and testing out on D. P's. Methods of testing, localising, and clearing faults in cables. Use and proper care of tools.

(d) *Overhead Line Section.*

Description of the different classes of poles, arm, insulators, and fittings used by the Department. Methods of erection. Special precautions to be used in handling reinforced concrete poles. Conditions necessitating use of stays and struts. Determination of staying requirements for angle and terminal poles. Use of copper, bronze, and iron wire. Methods of erection, regulation, binding in a termination. Different types of joint. Correct use of soldering bolt and special wiring tools. Inductive disturbances on telephone loops, and how prevented by means of (a) twist system, and (b) transposition system. Cable distribution poles. Protection of wires crossing power circuits. Use of safety belts and rubber gloves. Procedure to be adopted in case of accident or electric shock

A New Contribution to the Rational Design of Telephone Cables[1]

By D. P. DALZELL

Development and Research Laboratories, International Telephone and Telegraph Corporation

TELEPHONE cables were first introduced for urban communication in the form of "loop cables" consisting of a large number of pairs of small gauge conductors. When, however, communication by telephone between different towns became important, large gauge conductors were used in open wire lines owing to the necessity of reducing the conductor resistance to as low a value as possible. Open wire lines are, however, unsuited to the handling of a dense traffic and are likely to be damaged by storms. Both these conditions made the use of cables for interurban telephony very desirable and this was accomplished by the introduction of loading and the use of phantom circuits, so that the strength, quality and number of the received messages could very greatly exceed what could be obtained in similar circumstances with loop cables. These improvements, however, not only affected the message proper, but also improved the transmission of disturbances from other circuits caused, largely, by capacity unbalances, i.e., by irregularities in the distribution of capacities between the conductors of any circuit and those of other circuits. The way capacity unbalances cause mutual disturbances between circuits may be understood by regarding the two wires, say, of each of two pair circuits to be at opposite corners of a Wheatstone bridge with, however, capacities in the various arms instead of resistances. There must, then, be a relation of symmetry between the capacities involved when currents in one pair circuit do not generate potential differences in the other. In cables there are always unavoidable irregularities in the distribution of the capacities between the various conductors and capacity unbalances between the various circuits result.

The effects of capacity unbalances were still more aggravated by the introduction of repeaters and could in certain circumstances produce singing, which may occur when there is a possibility of the output circuit of a repeater influencing the input circuit; capacity unbalances provide a means of such influence.

The reduction of capacity unbalances thus became a matter of the first importance and has led to developments in the manufacture of cables greatly in advance of the methods formerly employed for loop cables. Uniformity in both the electrical and mechanical properties of the copper conductors is secured as far as manufacturing conditions permit and the possible influence of any residual irregularities is minimised by making the two wires of a pair from halves of the same continuous length of wire, while in the insulating process, these two wires are passed in immediate succession through the same machine. Similarly the strips of paper used for insulating the two wires of a pair are taken from adjacent positions in the original roll from which they are cut. By these, and similar methods, the greatest care is exercised for ensuring the maximum degree of similarity between the various conductors associated together in pairs, quads or other collective units. In this way cables were produced which could satisfactorily be used for transcontinental telephony. Detailed inspection of the quality of cables showed, however, that something was still lacking, for some types of capacity unbalances would sometimes have unexpectedly high values. The cause of this was traced, after exhaustive statistical examination of results, to the occurrence of peculiar combinations of twist lengths in the various pairs or quads of the cable. Mathematical investigation of the phenomenon was initiated and the problem was satisfactorily solved by the methods expounded below.

Considerations Introductory to the Theory of Capacity Unbalances

The construction of a theory of capacity unbalances depends upon a preliminary examination of the effect of twisting upon the set of direct capacities in a system of twisted circuits. Consider, first, four parallel wires W_1, W_2, W_3, and W_4, whereof W_1 and W_3 are alike and are to be considered as one pair circuit and W_2 and W_4 are alike and to be considered as another pair circuit. Suppose that the plane of the pair W_1W_3 make an angle of θ_1 with a fixed plane parallel to all four wires and that the plane of the pair W_2W_4 make an angle θ_2 with the same fixed plane, as shown in the figure. Then any one of the uniformly distributed direct capacities measured, say, in microfarads per mile between one of W_1 and W_3 and one of W_2 and W_4 is a function of θ_1 and θ_2 and of these alone, if they be the only variable elements of the system.

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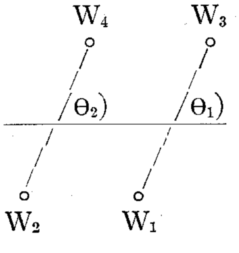
[1] Presented before World Engineering Congress, Tokyo, Section 6, October 30, 1929.



Thus the distributed direct capacity C_{12} between W_1 and W_2 may be written as

$$C_{12}=f\ (\theta_1\ \theta_2)$$

where
$$f\ (\theta_1+2\pi,\ \theta_2)=f\ (\theta_1,\ \theta_2)$$
$$f\ (\theta_1,\ \theta_2+2\pi)=f\ (\theta_1,\ \theta_2)$$

because a rotation of one complete turn of either pair leaves the system unaltered.

The two wires W_1 and W_3 are interchanged by a rotation of one half so that

$$C_{22}=f\ (\theta_1+\pi,\ \theta_2)$$

Similarly the two wires W_2 and W_4 are interchanged by a rotation of one half turn so that

$$C_{14}=f\ (\theta_1,\ \theta_2+\pi)$$
$$\text{and } C_{34}=f\ (\theta_1+\pi,\ \theta_2+\pi)$$

Thus all the four distributed direct capacities are expressible in terms of one function.

The uniformly distributed capacity unbalance between the two circuits, measured in microfarads per mile may be taken to be $U\ (\theta_1,\ \theta_2)$ where $U\ (\theta_1,\ \theta_2)=C_{12}+C_{34}-C_{32}-C_{14}$

Thus, substituting the expression found above for the distributed direct capacities, we have

$$U\ (\theta_1,\ \theta_2)=f\ (\theta_1,\ \theta_2)+f\ (\theta_1+\pi,\ \theta_2+\pi)$$
$$-f\ (\theta_1+\pi,\ \theta_2)-f\ (\theta_1,\ \theta_2+\pi)$$

Now since

$$f\ (\theta_1+2\pi,\ \theta_2)=f\ (\theta_1,\ \theta_2)$$

and $f\ (\theta_1,\ \theta_2+2\pi)=f\ (\theta_1,\ \theta_2)$ the function $f\ (\theta_1,\ \theta_2)$ is periodic in each of the two variables θ_1 and θ_2 and may be expressed in the form of a multiple trigonometric series, say

$$f\ (\theta_1,\ \theta_2)=\sum_{m,n} C_{m,n}\cos\ (n\theta_1+\beta_n)\ \cos\ (m\theta_2+\beta_n)$$

where n and m are integers and $C_{m,n}$, β_n and β_m are independent of θ_1 and θ_2; or, substituting for the products of cosines by means of the addition theorem for the cosine function, we get

$$f\ (\theta_1,\ \theta_2)=\sum_{m,n} C'_{m,n}\ \cos\ (n\theta_1+m\theta_2+\eta_{m,n}$$

when $C'_{m,n}$ and $\eta_{m,n}$ are independent of θ_1 and θ_2.

Basic Assumptions and the General Theory

This result must now be applied to the consideration of twisted circuits. The lengths of twist may be supposed to be long compared with the lateral dimensions of the circuits in question, and with this supposition the distributed direct capacities at a given place may be taken to be identical with those of an untwisted system whose configuration is the same as that of the system of twisted circuits at that place. This procedure does not differ from the usual neglect of "end effects" involved in the investigation of three dimensional physical systems by means of an imaginary two-dimensional system. Then, at a place where the inclinations of the twisted circuits to a fixed plane are θ_1 and θ_2, the distributed unbalance, or local unbalance may be taken to be $U\ (\theta_1,\ \theta_2)$ as defined above, where now θ_1 and θ_2 are no longer invariable but can be expressed in terms of the distance $\varkappa$ along the circuit; thus

$$\theta_1=\frac{2\varkappa}{T_1}+\alpha_1$$

$$\theta_2=\frac{2\varkappa}{T_2}+\alpha_2$$

where T_1 and T_2 are the lengths of twist of the pairs W_1W_3 and W_2W_4 respectively and α_1 and α_2 are the values of θ_1 and θ_2 when $\varkappa=0$.

The result of the preceding article may be stated, by extension, to be that in a perfectly twisted set of circuits, a local capacity unbalance U between two such circuits of the set may be represented by a trigonometric series, so that, say

$$U = \Sigma C\ (n_1\, n_2 \ldots\ldots\ldots\ldots\ldots\ldots n_N) \cos \left\{ \left(\frac{2\pi n_1}{T_1} + \frac{2\pi n_2}{T_2} + \ldots\ldots \frac{2\pi n_N}{T_N} \right) \varkappa + \eta\ (n_1\, n_2 \ldots\ldots n_N) \right\}$$

where the numbers C $(n_1\, n_2 \ldots\ldots n_N)$ are the constant coefficients of the series, and the numbers η $(n_1, n_2 \ldots\ldots n_N)$ are the phase constants. The integers $n_1\, n_2 \ldots\ldots n_N$ may be positive, negative or zero. The numbers $T_1\, T_2\, T_3 \ldots\ldots T_N$ are the various lengths of twist, which may be considered to affect the unbalance, T_1 and T_2 being, say, the lengths of twist of the two circuits under consideration and the other twist lengths being those which may affect, for example, the distance between these two circuits, and generally represent the effect of any circumstance which may have a periodic influence upon the mutual relations of the two circuits.

In order somewhat to simplify notation the various terms of the trigonometric series may be renumbered by means of a single suffix v, so that $U = C_v \cos\ (2\pi\xi_v\, \varkappa + \eta_v)$

where $\xi_v = \frac{n_1}{T_2} + \frac{n_2}{T_2} + \ldots\ldots \frac{n_N}{T_N}$

where the single integer v corresponds with the set of integers $n_1\, n_2 \ldots\ldots n_N$. The numbers ξ_v are called compounded torsions, and when the twist lengths are in inches, the compounded torsions represent revolutions per inch. The total unbalance over a distance X would then be obtained simply by integration, if the assumption of perfect twisting were maintained. This assumption is, however, in no case legitimate, and some discussion should be made of the nature of irregularities in twisting and of the appropriate theoretical treatment. A single term in the series whose sum represents the local unbalance is

$$C_v \cos\ (2\pi\xi_v\, \varkappa + \eta_v)$$

where ξ_v depends upon the integers $n_1\, n_2 \ldots\ldots n_N$ so that

$$\xi_v = \frac{n_1}{T_2} + \frac{n_2}{T_2} + \frac{n_2}{T_3} \ldots\ldots\ldots\ldots \frac{n_N}{T_N}$$

Clearly the amplitude C_v and the phase constant η_v of this term are illdetermined when any one of the numbers $n_1\, n_2 \ldots\ldots n_N$ is large, and in practice these numbers can be fixed in value for a considerable distance only when $n_1\, n_2 \ldots\ldots n_N$ are all fairly small. The actual state of affairs is not precisely known, but we may suppose for purposes of calculation, that with each compounded torsion ξ_v is associated, in a given set of circuits, a series of spans each of length σ_v in which the amplitude C_v and phase constant η_v in the term

$$C_v \cos\ (2\pi\xi_v \varkappa + \eta_v)$$

are both constant, but that the values are independent in any two distinct spans, subject, however, to the limitation that the mean square of all values of C_v in the various spans of the various pairs of circuits is A^2_v.

In order to complete the succeeding calculations an assumption concerning the spans σ_v for the various sets of circuits is required. In this case, we shall use the following law of distribution,

$$dP = h_v^2 \sigma e^{-h_v^2 \sigma} d\sigma$$

for the span σ_v associated with a given compounded torsion ξ_v, so that dP is the proportion of the whole number of pairs of circuits for which the span σ_v lies in the range $(\sigma,\ \sigma + d\sigma)$. In this case, the constant h_v is connected with the mean span, denoted by t_v, by the equation

$$h_v\, t_v = 2$$

Although the assumptions seem to be only slightly connected with the conception of continuous variation of the compounded torsions and the amplitudes, yet the final results required are only those dependent upon average values and may be accepted as of the correct general form.

We proceed, then, by recalling that the local distributed unbalance is represented by a series

$$U = \sum_v C_v \cos\ (2\pi\xi_v \varkappa + \eta_v)$$

For one span from

$$\varkappa - \tfrac{1}{2}\, \sigma_v \text{ to } \varkappa + \tfrac{1}{2}\, \sigma_v$$

the resultant unbalance $\overline{U}$ is given by integration, so that

$$\overline{U} = \sum_v \frac{C_v}{\pi\xi_v} \sin \pi\xi_v\, d_v \cos\ (2\pi\xi_v \varkappa + \eta_v)$$

The number of spans of length σ_1 in a length X is between

$$\frac{X}{\sigma_1} - 1 \text{ and } \frac{X}{\sigma_1} + 1$$

so that if $\frac{X}{\sigma_v}$ be large, it may be taken as the number of spans in a circuit of length X.

Thus, in a given circuit, the unbalance associated with a given compounded torsion ξ_v will result from $\frac{X}{\sigma_v}$ terms each resulting from one span. The mean square unbalance in a group of circuits all having the same span σ_v associated with the torsion ξ_v may now be written down as

$$X \sum_v \frac{A^2_v}{2\pi\xi^2_v\sigma_v} \sin^2 \pi\xi_v\sigma_v$$

Our assumption concerning the distribution of spans then leads to the final approximate expression for the root mean square value M of all unbalances.

$$M^2 = X \sum_v \frac{A^2_v}{2\pi\xi^2_v} \int_0^\infty (\sin \pi\xi_v\sigma)\, h^2_v\, e^{-h_v\sigma} d\sigma$$

$$= X \sum_v \frac{A^2_v\, h^v}{h_v^2 + 4\pi^2\xi_v^2}$$

When the mean span t_v is inserted instead of h_v where

$$h_v\, t_v = 2$$

the final result is

$$2M^2 = X \sum_v \frac{A^2_v\, t_v}{1 + \pi^2 t^2_v \xi_v^2}$$

Deductions from the General Theory

In the formula for the mean square unbalance M^2 our sole concern is the mode of variation of the root mean square unbalance M^2 with the lengths of twist involved in the compounded torsions ξ_v when the various coefficients and the other variables have fixed values. In these circumstances the individual term

$$\frac{A^2_v\, t_v}{1 + \pi^2 t_v^2 \xi_v^2}$$

attains its greatest value

$$A^2_v\, t_v \qquad \text{when } \xi = 0.$$

According to the present theory, this condition is precisely the one to be avoided, and is called a "critical condition." The whole set of critical conditions depends upon the original choice of the aggregate of trigonometrical terms used to represent the given configuration of circuits and little consideration is needed to show that many of the critical conditions must be superfluous. Thus the complete representation of a periodic function involves, in general, an infinite number of terms of successively decreasing periods, and there must certainly be a period sufficiently short to preclude the possibility of its accurate determination in the manufacture of telephone cable, and this state of affairs is represented in the theory by the use of a short mean span.

Consider now the expression for M^2 as a function of one of the twist lengths, say T_1, involved in it. Each term in the series for M^2 which involves T_1 in a suitable manner will attain a maximum value for some one value T_1.

Then M^2 is the sum of a number of terms each with single maxima for various values of T_1 and there is, on general mathematical grounds, no reason to suppose that the maxima of the sum of the series for M^2 will occur in the neighbourhood of the maxima of the individual terms unless the latter are very marked. The sharpness of the maxima of the individual terms depends upon the values of the mean span, that is, upon the consistency with which the successive periods involved in the compounded torsion are reproduced. In the light of these remarks the theory may be said to lead to the conclusion that the collection of all critical conditions derived from the most general trigonometric representation of the system of circuits indicates all the possibilities of systematic occurrence of exceptionally large unbalances between circuits of a telephone cable owing to peculiarities in the system of twists, but that only a small number of these possibilities are realised. In order to anticipate which of the critical conditions must, in fact, be considered, recourse to observation is not necessary except by way of confirmation of our conclusions.

Consider a system of circuits involving n twist lengths $T_1\, T_2 \ldots\ldots\ldots T_n$. Then the capacity unbalance between two circuits of the system may be regarded as depending on some or all of these n twist lengths, and any one compounded torsion ξ will be of the form

$$\xi = \frac{n_1}{T_1} + \frac{n_2}{T_2} + \ldots\ldots\ldots \frac{n_N}{T_N}$$

where $n_1\ n_2 \ldots\ldots\ldots n_N$ are integers, positive, negative or zero.

The values of $n_1\ n_2 \ldots\ldots\ldots n_N$ greater than unity are associated with periods which are submultiples of the fundamental twist lengths or periods and the corresponding term in the trigonometrical series is associated with a long mean span only when the shapes of the circuits in successive twist lengths or periods are accurately similar. Owing to unavoidable slight variations in the properties of raw materials, and in the effects upon them of the manufacturing processes and to the complication of the structure of the complete cable, this consistency can hardly be supposed to be maintained. Thus we may anticipate that, in ordinary cases, the only compounded torsions to be considered are those of the form

$$\xi = \pm\frac{1}{T_{r1}} \pm \frac{1}{T_{r2}} \pm \frac{1}{T_{r3}} \pm \ldots\ldots\ldots \pm \frac{1}{T_{r_s}}$$

where the twist lengths involved are all or some of total of n twist lengths.

A compounded torsion which does not involve fractions of the lengths of twist is called a torsion of the first order.

Thus we may enunciate the principle that only critical conditions of the first order need consideration, and that these critical conditions are to be deduced from a trigonometric expression for the local unbalances. As an example of the formulation of critical conditions a convenient example is that of capacity unbalance between the phantom of one quad and a pair of an adjacent quad in a quadded cable. In this case, let T_1 and T_2 be the phantom twists of the two quads and let T be the pair twist of one of the pairs in the quad whose phantom twist is T_1. In this case, the local unbalance may be represented by a trigonometric function of the form

$$\left\{a + b\cos\left(\frac{2\pi\varkappa}{T_1} + \eta_1\right)\right\}\cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right)\cos\left(\frac{2\pi\varkappa}{T} + \eta\right)$$

where a, b, η, η_1 and η_2 vary only slightly with $\varkappa$. The construction of the above expression may be explained by noting that if the pair were not in a quad then b would be zero. The fact that the pair is one of two pairs in its quad means that its distance from the other quad varies with a period T_1 and this variation is represented by the term whose coefficient is b. This expression is the sum of two parts; one part is

$$a\cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right)\cos\left(\frac{2\pi\varkappa}{T} + \eta\right)$$

and leads to the commonplace critical equation

$$T = T_2$$

The second part is

$$b\cos\left(\frac{2\pi\varkappa}{T} + \eta\right)\cos\left(\frac{2\pi\varkappa}{T_1} + \eta_1\right)\cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right)$$

and when rearranged by means of the addition theorem for the cosine function involves compounded torsions of the form

$$\xi = \pm\frac{1}{T} \pm \frac{1}{T_1} \pm \frac{1}{T_2}$$

and the critical equations are of the form

$$\xi = 0.$$

Of the various equations which result, two only are possible; these are

$$T = \frac{T_1T_2}{T_1 - T_2} \quad \text{and} \quad T = \frac{T_1T_2}{T_1 + T_2}$$

Thus there are two critical twist lengths for the pair, both of which would be associated with abnormally large values of capacity unbalance between that pair and the neighbouring phantom.

The Indicial Theory

When the assumption is made that only torsions of the first order are to be considered the critical conditions may be deduced very simply. Thus, suppose that a system of circuits involve the twist lengths of periods $T_1\ T_2 \ldots\ldots\ldots T_n$ so that a term in the trigonometrical representation of the local unbalance is of the first order and of the form

$$\cos\left(\frac{2\pi\varkappa}{T_1} + \eta_1\right)\cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right) + \ldots\cos\left(\frac{2\pi\varkappa}{T_n} + \eta_n\right)$$

When this expression is rearranged by means of the addition formula for the cosine it becomes

$$\frac{1}{2^{n-1}}\sum_{p}\cos\left(2\pi\xi_p\varkappa + \lambda_p\right)$$

where ξ_p are the 2^{n-1} first order torsions derived from $T_1, T_2 \ldots\ldots\ldots T_n$.

Integration over a span of length σ then gives

$$\frac{1}{2^{n-1}}\sum_{p}\frac{\sin 2\pi\ \xi_p\sigma}{\pi\ \xi_p}\cos\left(2\pi\ \xi_p\varkappa + \lambda_p\right)$$

and the mean square of this last expression with respect to independent variations of σ and $\varkappa$ is

$$\frac{1}{\pi^2 2^{2n}} \sum_p \frac{1}{\xi^2_p}$$

and this last expression becomes infinite when

$$\xi_p = 0.$$

We may call the reciprocal of ξ_p a compounded twist length, and the root mean square J of all compounded twist lengths may be called the index, so that

$$2^{n-1}\, J^2 = \sum_p \frac{1}{\xi^2_p}$$

Thus the critical conditions are summed up in the equation $J = \infty$ where J is any index derived from the twist lengths and periods involved in the system of circuits.

The method of constructing the index may be used with advantage in the considerations of a case not included conveniently in the general analysis. When the two circuits are in adjacent layers they only approach each other at regular intervals so that two successive points of approach are separated by a fixed distance R. In this case the index may be constructed by summation and not by integration. As before, a term in the trigonometrical representation of the local unbalance of the form

$$\cos\left(\frac{2\pi\varkappa}{T_1}+\eta_1\right)\cos\left(\frac{2\pi\varkappa}{T_2}+\eta_2\right)\ldots\cos\left(\frac{2\pi\varkappa}{T_n}+\eta_n\right)$$

may be rearranged as

$$\frac{1}{2^{n-1}} \sum_p \cos\,(2\pi\xi_p\varkappa+\lambda_p)$$

Now by summing over N points of contact the following expression is obtained

$$2^{-n+1} \sum_p \sum_{r=0}^{r=N-1} \cos\left\{2\pi\xi_p\,(\varkappa+rR)+\lambda_p\right\}$$

$$=2^{-n+1} \sum_p \frac{\sin N\pi\xi_p R}{\sin \pi\xi_p R} \cos\,(2\pi\,\xi_p\varkappa+N\pi\xi_p R+\lambda_p)$$

The mean square value of this for variations of $\varkappa$ is, accordingly

$$2^{-2n+1} \sum_p \frac{(\sin N\pi\xi_p R)^2}{\sin \pi\xi_p R}$$

and, finally when N is large the mean for small variations of R is

$$2^{-2n+1} \sum_p \operatorname{cosec}^2\,(\pi\xi_p R)$$

and thus the index J can, in this case, be defined as a mean square by the equation

$$2^{n-1}\, J^2 = \pi^2 R^2 \sum_p \operatorname{cosec}^2\,(\pi\xi_p R)$$

The critical equations are then of the form

$$J = \infty,$$

which is the case when, and only when

$$R\xi_v = m$$

for some compounded torsion ξ_v and some integer m, positive, negative or zero.

In the particular case of two circuits of twist lengths T_1 and T_2 in contact only at points at equal distances R apart, and unaffected by any periodic influence, the critical equations are

$$\frac{1}{T_1} \pm \frac{1}{T_2} = \frac{m}{R}$$

where m is an integer.

Concluding Remarks

The various cases treated above both by the general analysis and by the indicial theory constitute the whole present extent of the theory, so far as it is relevant to the usual conditions in a telephone cable. Some of the simpler cases can be treated by an elementary geometrical method but this treatment has the defect that the operating causes are not analysed and examined; whereas the more elaborate treatment has the advantage that, by obtaining an expression for total unbalance from a definite scheme of basic assumptions, all possibilities resulting from these assumptions are found.

The theory, being based merely upon an examination of the way various periodicities interfere, is not restricted to any one type of cable and can be applied to paired cable, spiral four cable, quaded cable and other similar types, so that a considerable range of cable design acquires a certainty which, before, could not be attained.

In many cases the application of the theory has not only removed exceptionally or unexpectedly large values of unbalance, but has effected an all-round improvement, as represented by averages, of 50% in some types of capacity unbalance.

Czechoslovakian Cable System

By F. J. STRINGER, W. F. MARRIAGE and E. L. E. PAWLEY

European Engineering Department, International Standard Electric Corporation

THE Republic of Czechoslovakia comprises three main regions: Bohemia in the west, Moravia in the centre, and Slovakia in the east. The chief cities of these regions are Prague, Brno, and Bratislava, respectively.

Bohemia and Moravia have a number of important manufacturing centres, producing machinery, textiles, beer, pottery, chemicals, and high quality glass. Highly developed coal and iron fields exist in these regions. Sugar beet is produced on a large scale, and many sugar factories are distributed throughout the country.

Slovakia is chiefly agricultural, and includes large tracts of forest. There are several important manufacturing cities; the boot and shoe industry is one of the best developed in the world. Slovakian factories export shoes to practically all European countries and to America.

The Republic, which celebrated in 1928 the tenth anniversary of the recovery of its independence, has made remarkable progress during the past decade, and its industries are developing rapidly. A striking sign of the rapidity of the growth of prosperity is that the business and shopping quarters of the capital have been practically rebuilt in the last few years, large modern buildings taking the place of the older ones which no longer suited the new conditions.

It was realised early by the Czechoslovakian Administration that a really efficient long distance telephone service between the chief centres would materially help in the development of the Republic, and plans were drawn for connecting these by a modern toll cable network.

Further, Czechoslovakia is so situated in the centre of Europe, having boundaries to no fewer than five neighbouring countries, that it forms a natural highway of international communication. Czechoslovakia itself has, of course, a large volume of business with its neighbours, necessitating terminating international circuits, but in addition, it offers the best means of communication between the northern and southern neighbouring countries, so that an important transit international traffic was to be expected.

The Administration plans, therefore, were to connect Prague, Brno and Bratislava in the first case, and also to provide connections with Germany via Lovosice, and Dresden, Austria, via Břeclav and Vienna, and Hungary via Bratislava. At the same time, the ultimate requirements were carefully studied so that the first cables should form part of a well planned general scheme covering the whole of the Republic and properly coördinated with the networks of the neighbouring states.

Figure 1 shows the general plan of the Czechoslovakian cable network, and indicates the extent to which the project has been carried out up to the present date.

The cables were manufactured in Czechoslovakia at the following three cable factories, viz.,

Bratislava Kabelfabrik A. G.
Kablo Aktien-Kabel-und-Drahtseil-Fabrik, Kladno.
Fr. Krizik, Kabelfabrik und electrotechnische Werke, Bodenbach.

In order to carry out the installation of the cables and loading coils, the Long Distance Cable Construction Company (L. D. C. C. Co.) was formed, and the whole of this work was done by Czechoslovakian labour.

The orders for the repeater equipment and loading coils were placed on the Hekaphon Western Electric, Praha, Vrsovice (now the Standard Electric Doms a Společnost.)

The repeater equipment was manufactured by the Bell Telephone Manufacturing Company of Antwerp, and was installed by the Long Distance Cable Construction Company with the aid and advice of the Antwerp Company, which also provided a number of skilled installers for this work.

The loading coils were manufactured by Standard Telephones & Cables, Ltd., of London,

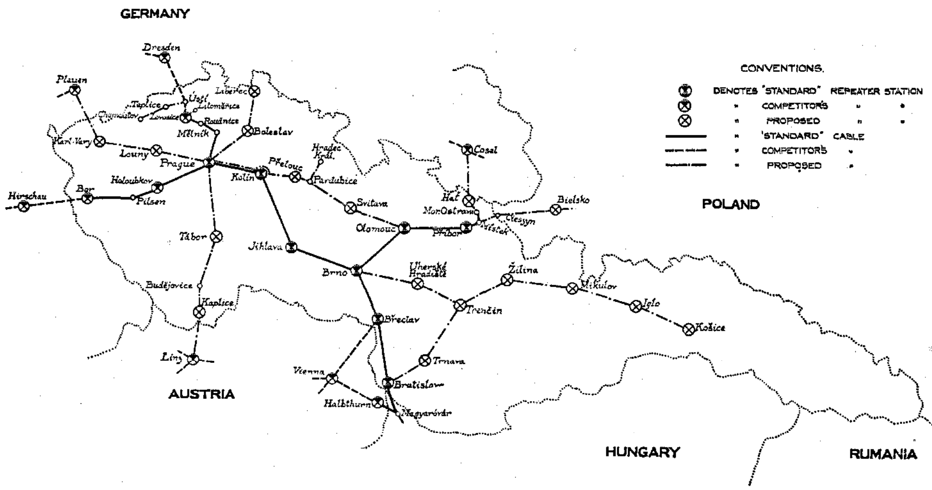


Figure 1—Czechoslovakian Toll Cable System, 1929.

by the Bell Telephone Manufacturing Company of Antwerp, and by Le Matériel Téléphonique of Paris.

The first part of the network to be installed was the Prague-Kolín cable. This cable, in common with all subsequent cables in the Republic, excepting only those sections which actually cross the Austrian and German frontiers, is of "Standard" type, and was manufactured and installed with the advice of the International Standard Electric Corporation.

During the manufacture of the cable, schools were started for training the jointers and testers who were supplied either by the Administration, or by the Cable Companies. The schools were continued for two months, so that when the

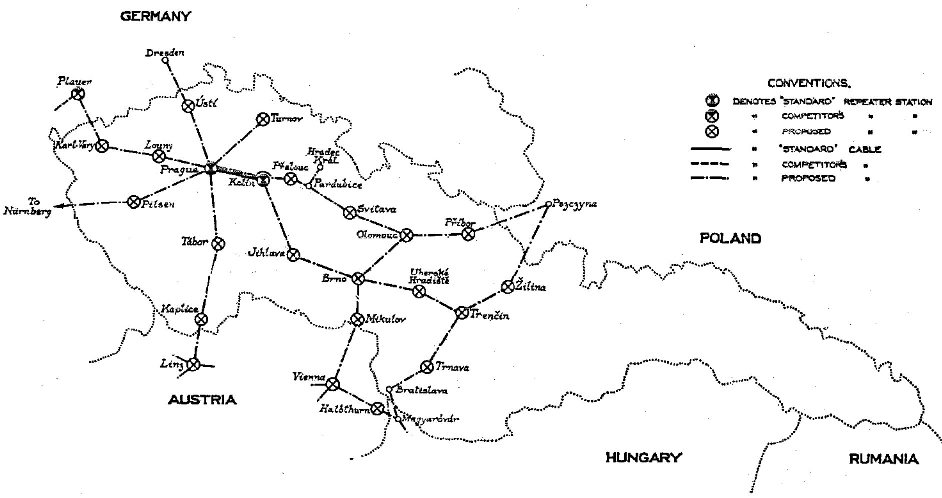


Figure 2—Czechoslovakian Toll Cable System, 1925.

manufacture of the cable was sufficiently advanced, a trained staff was available to commence installation. Installation of this first cable was started in August, 1925, since which time a total of 857.3 Kms. of toll cable has been laid in Czechoslovakia.

The map of Czechoslovakia (Figure 1) in addition to the existing cable routes shows those on which it is proposed to lay cable in the near future. A glance at this map reveals the extensive development of long-distance facilities which is being carried out by the Czechoslovakian Administration. It is interesting here to compare Figure 1 with Figure 2, which shows the cable routes of 1925.

General Description

The map in Figure 1 shows in full lines the routes followed by the cables, and indicates the spacing of the repeater stations.

The survey of the first cable route, Prague-Kolín, was carried out jointly by the International Standard Electric Corporation, and the L. D. C. C. Co., whilst subsequent surveys were made entirely by the L. D. C. C. Co.

The cable is armoured, and is laid throughout direct in the ground. The trench following the side of the road or along a footpath was dug by manual labour to a depth of 80 centimetres, and is about 30 centimetres wide. The depth was increased at road crossings and in towns to about 120 centimetres. After the cable had been placed, a covering of 10 centimetres of sifted earth was thrown in prior to filling. In the open country, further protection is provided by a layer of bricks, placed transversely across the cable, as shown in Figure 3, whilst in the towns, rectangular concrete channel blocks with removable tops are provided. At bridge crossings, the cable either is protected and supported with iron troughing, as shown in Figure 4, or is pulled into iron piping. Joints in the armoured cable other than at the loading points are protected by means of split couplings of cast iron buried directly in the earth.

Horse-drawn wagons or motor tractors were used for laying the cable in the trench; the former method is shown in Figure 5.

The following table gives details of the various cables installed, and indicates the dates when the various sections were commenced and completed. It will be noted that the first cable to be installed was between Prague and Kolín. It was opened for service in May, 1926, and was extended to Jihlava a year later, service over the Prague-Jihlava section being opened in May, 1927. The growth of the traffic was so rapid that a second installment of loading had to be added, and this was completed in October, 1928.

CABLE SECTION	Length in Kms.	CABLE SIZE			Radio	INSTALLATION DATES	
		1.3 mm. quads 2-wire	0.9 mm. quads 2-wire	0.9 mm. quads 4-wire		Commenced	Completed
Lovosice-Prague	75.3	36*	6	30	1 LC quad 0.9 mm.	Oct. 1926	Nov. 1927
Prague-Kolín	56.9	44	6	26	....	Oct. 1925	May 1926
Kolín-Jihlava	82.1	37	6	30	....	May 1926	Oct. 1928
Jihlava-Brno	87.7	37	6	30	....	April 1927	Oct. 1928
Brno-Břeclav	61.3	20	18	40	1 screened pair 1.3 mm.	Aug. 1927	Oct. 1928
Břeclav-Bratislava	81.7	11	5	16	1 screened pair 1.3 mm.	Sept. 1927	Oct. 1928
Bratislava Frontier	9.3	12	4	16	....	May 1927	Oct. 1927
Brno-Olomouc	73.9	36	6	30	2 screened pairs 1.3 mm.	April 1928	Oct. 1928
Olomouc-Mistek	91.0	20	12	46	2 screened pairs 1.3 mm.	May 1929	....
Mistek-Mor Ostrava	20	11	6	40	1 screened pair 1.3 mm.	....	....
Prague-Pilsen	94.0	36*	6	30	1 LC quad 0.9 mm.	May 1928	May 1929
Pilsen-Bor	51.2	20*	6	22	1 LC quad 0.9 mm.	Aug. 1928	May 1929

* 1.4 mm. Conductors.

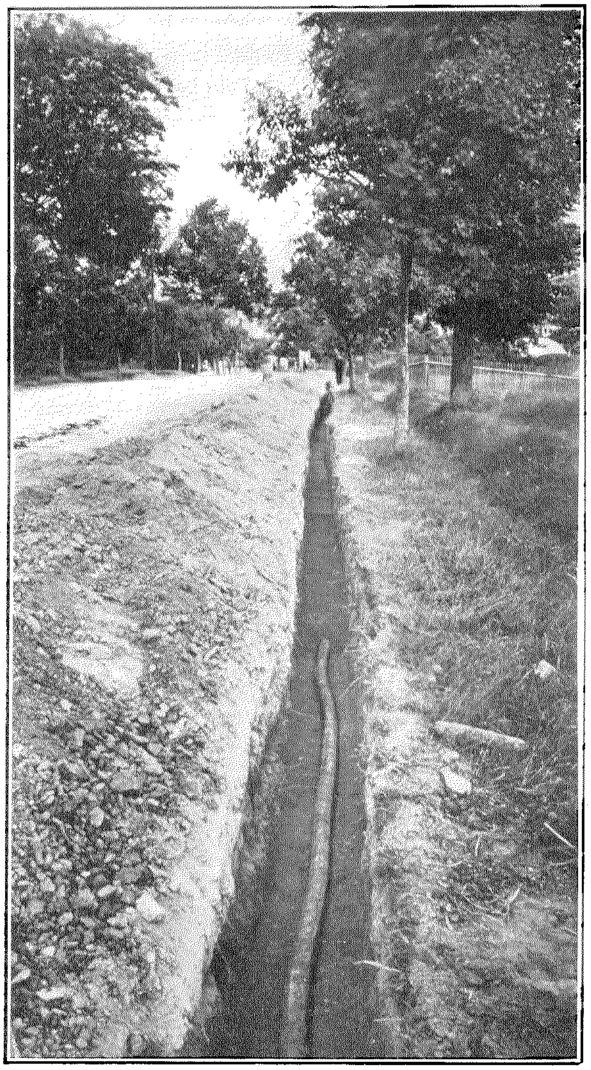


Figure 3—Cable Trench During Filling Operation.

Cross section diagrams of the various cables are seen in Figure 6.

All the cables in Czechoslovakia, with the exception of the sections crossing the German and Austrian frontiers, were installed in accordance with the cross-splicing method of reducing capacity unbalances. Test joints were made in each loading section for capacity unbalance reduction, and in addition, the circuit capacity deviations were reduced at the centre joint of each loading section. The usual direct current tests were made for insulation and copper resistance. Figures 7 and 8 show testers and jointers at work.

Two types of loading were used on the cable, viz., H-177-63 and H-44-25,[1] on a spacing of approximately 1,830 metres. Broadcasting circuits were loaded with 15.5 mH coils for 1.3 mm. screened pairs, and with 177-9.5 units for 0.9 mm. screened quads. Figure 9 shows the method of connecting the single stub cable to the main cable. This method enables the loading coil case to be connected to the cable without undue congestion of the joints. Figure 9 also indicates the type of concrete loading coil manhole used throughout the job.

Figure 10 shows a loading coil case being lowered into such a manhole as that depicted in Figure 9.

Figure 11 shows a pressure test being made on the cable.

The cable is designed to provide three types of circuit:

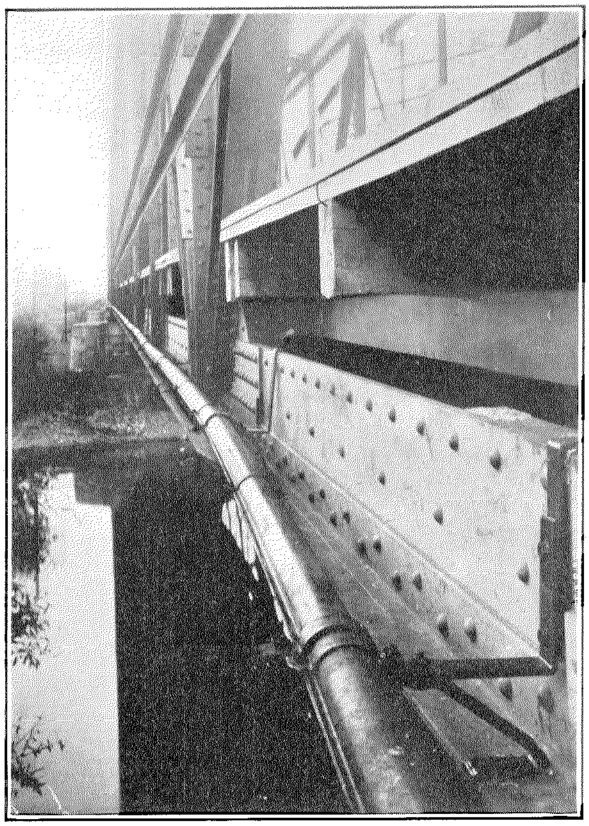


Figure 4—Bridge Crossing with Iron Troughing.

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[1] For explanation of designations, see "Development and Application of Loading for Telephone Circuits," by Thomas Shaw and William Fondiller, *Electrical Communication*, April, 1926, pp. 258–276, and July, 1926, pp. 38–53.

(a) two-wire loaded H-177-63 for the shorter circuits.
(b) four-wire loaded H-177-63 for long distance traffic.
(c) four-wire loaded H-44-25 for international traffic.

The total number of toll lines at present in operation is about 157.

The extension of international circuits at present depends entirely upon the extent to which Administrations of surrounding countries take up the circuits.

The installation of the Prague-Lovosice cable placed Czechoslovakia in connection with the German cable network, and provided circuits from Prague to Berlin, Paris, and other important towns in northern and western Europe.

The Prague-Bratislava system links up Czechoslovakia with the Hungarian network via the Budapest-Bratislava cable, providing not only communication between the two countries, but transit traffic from northern and western Europe to Hungary. When the Hungarian cable between Budapest and Szeged is completed, this transit traffic will be extended through to the proposed Jugoslavian network to Belgrade and the Balkan States.

The completion of the Brno-Olomouc-German and Polish borders cable will provide circuits from Czechoslovakia, Austria (via the Vienna-Břeclav Cable) and Hungary to eastern Germany, Poland, and the Baltic States.

The Prague-Pilsen-Bor cable will provide circuits from Czechoslovakia to southern Germany, Switzerland, England, France, and Holland.

Repeater Equipment

There is a total of eleven repeater stations on the Czechoslovakian Toll Cable System, and so rapid has been the growth of traffic, that the initial equipment in many of these stations has had to be increased after a few months service. Of these eleven repeater stations, eight have been installed according to the "Standard" system.

The following table gives the principal items of repeater equipment at each station:

	4-wire Repeater		2-wire Repeater		V. F. Ringers		4-wire Term. Sets		20~ Ringers	
	Init.	Ult.	Init.	Ult.	Init.	Ult.	Init.	Ult.	Init.	Ult.
Prague	26	177	11	49	80	334	18	102	23	39
Kolín	16	39	56	90	5	9	2	2	65	84
Jihlava	21	47	27	39	..	..	..	..	25	37
Brno	26	118	62	100	16	20	1	4	27	32
Břeclav	15	59	43	81	..	..	..	..	31	41
Bratislava	9	17	7	14	10	18	1	2	5	7
Olomouc	10	57	16	41	8	5	..	..	17	35
Příbor			Equipment not		yet engineered					

The layout of the equipment in the repeater stations embodies the most up-to-date practices, the underlying aim having been to provide the maximum possible flexibility in the arrangement of the apparatus, so that any circuit or any arrangement of apparatus might be set up or modified.

With this end in view, the apparatus was assembled in groups of the same type, each group being terminated at the distributing frame, for connection by means of jumper wires into the required circuit combinations. Emergencies or unforeseen traffic demands can easily be met by simple changes in the jumper wiring. In order still further to increase the station flexibility, the equipment is so jacked that if for any reason any piece of apparatus breaks down, spare apparatus may be patched in with only a very short interruption of service.

The main cable is terminated at each repeater station by splicing it at a convenient point inside the station to several silk and cotton insulated lead covered cables which are so arranged as to maintain the segregation effected in the main cable, and which are connected to protectors on the combined distributing frame. From the protectors, the cable circuits are connected to the toll test board, shown in Figure 12, and thence through jacks to the repeating coils and the necessary circuit equipment.

The No. 5 Toll Test Board, which is installed in all stations except Kolín, contains testing equipment consisting of Voltmeter and Wheatstone Bridge circuits as well as facilities for talking and ringing on the cable circuits, and is so designed that routine tests and fault locations can be made quickly on any cable circuit. By means of its jack circuits, it also provides a rapid means for bringing into service spare circuits or equipment when necessary.

An article by Mr. A. B. Hart dealing with the London-Glasgow Trunk Cable[2] described in detail repeater station equipment, which is very similar to that installed on the Czechoslovakian cable system, and it seems unnecessary therefore to enter into a detailed description of this equipment in the present instance.

In all repeater stations, excepting the earlier installation in Kolín, unit type repeater and ringer bays are used. These bays are completely wired and tested in the factory, thus reducing the installation and testing work considerably.

Figures 12, 13, and 14 show views of some of the equipment at a typical repeater station. The Toll Test Board, combined distributing frame, and repeating coil rack are closely associated, so that the cable runs from the point of entrance of the cable to the repeating coils may be as short as possible in order to keep the danger of crosstalk between phantom and side circuits down to a minimum.

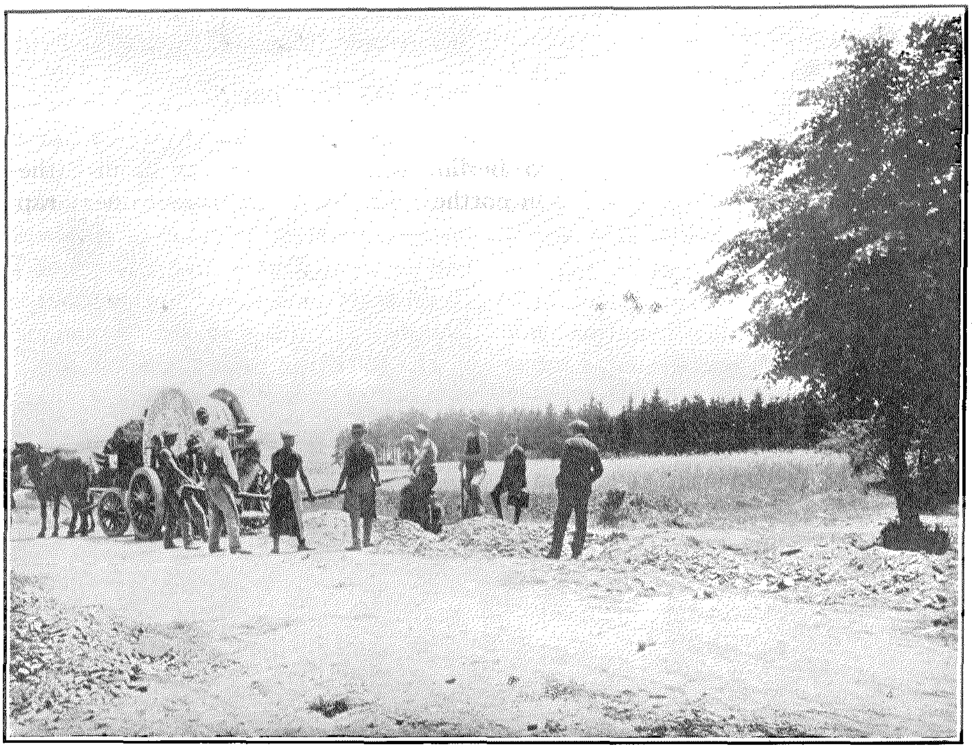
Figure 5—Horse-drawn Cable Wagon.

Adequate gangways are provided, and a sufficiency of space has been reserved for future extensions. In all stations racks are provided for No. 6 type Transmission Measuring Sets and associated No. 10 type Oscillators, this apparatus being used in making the line transmission tests as well as the station routine maintenance tests.

At all stations except Prague, the power plant provides current for the repeaters and their associated equipment only. At Prague, the main battery supplies both the repeater station and the manual exchange equipment, but it is planned to install separate power equipment for the

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[2] "The London-Glasgow Trunk Telephone Cable and its Repeater Stations," *Electrical Communication*, October, 1926, p. 119–156.

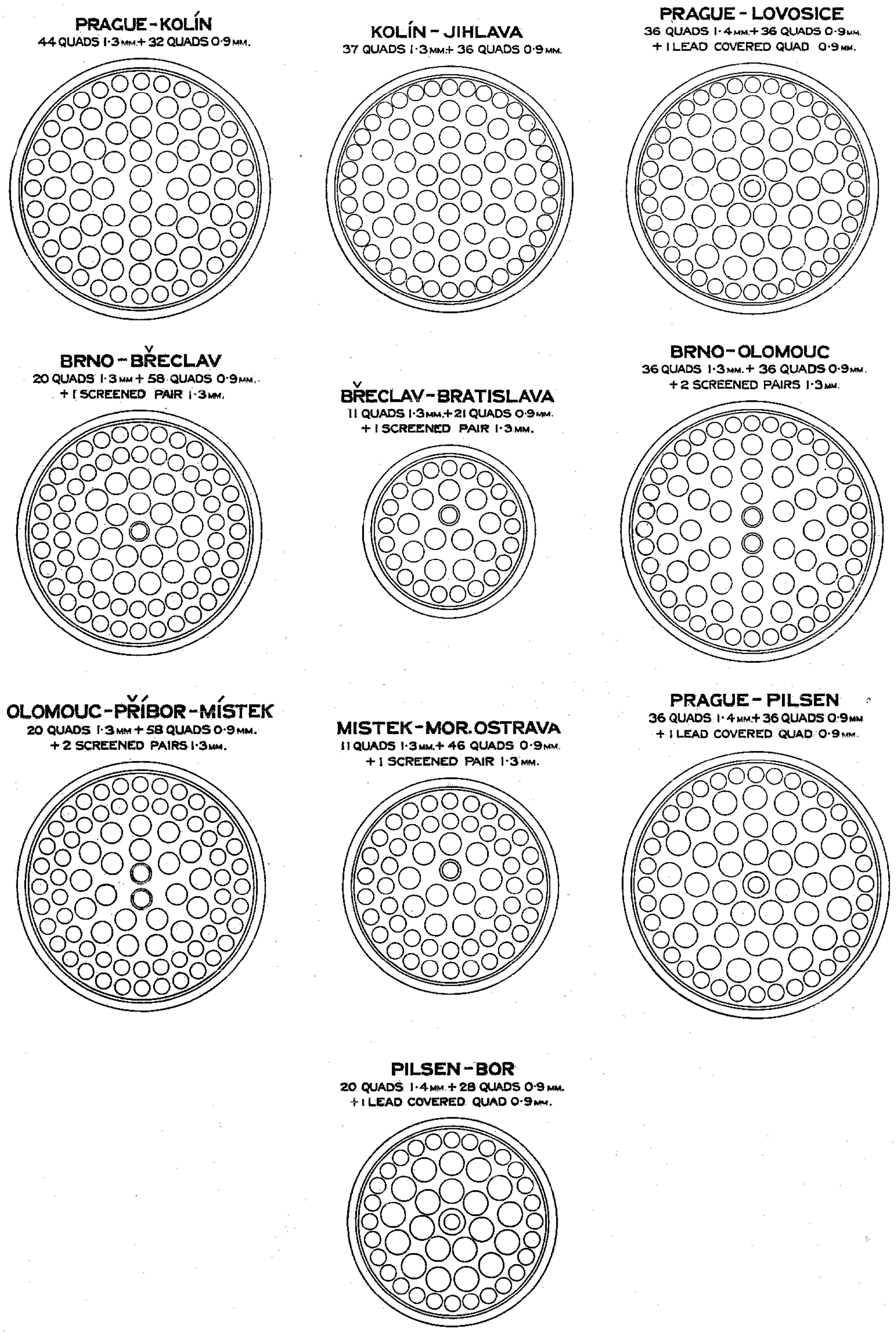

PRAGUE-KOLÍN
44 QUADS 1·3 MM.+ 32 QUADS 0·9 MM.
KOLÍN - JIHLAVA
37 QUADS 1·3 MM.+ 36 QUADS 0·9 MM.
PRAGUE - LOVOSICE
36 QUADS 1·4 MM.+ 36 QUADS 0·9 MM.
+ 1 LEAD COVERED QUAD 0·9 MM.
BRNO - BŘECLAV
20 QUADS 1·3 MM + 58 QUADS 0·9 MM.
+ 1 SCREENED PAIR 1·3 MM.
BŘECLAV-BRATISLAVA
11 QUADS 1·3 MM.+ 21 QUADS 0·9 MM.
+ 1 SCREENED PAIR 1·3 MM.
BRNO-OLOMOUC
36 QUADS 1·3 MM.+ 36 QUADS 0·9 MM.
+ 2 SCREENED PAIRS 1·3 MM.
OLOMOUC-PŘÍBOR-MÍSTEK
20 QUADS 1·3 MM + 58 QUADS 0·9 MM.
+ 2 SCREENED PAIRS 1·3 MM.
MISTEK-MOR. OSTRAVA
11 QUADS 1·3 MM.+ 46 QUADS 0·9 MM.
+ 1 SCREENED PAIR 1·3 MM.
PRAGUE-PILSEN
36 QUADS 1·4 MM.+ 36 QUADS 0·9 MM
+ 1 LEAD COVERED QUAD 0·9 MM.
PILSEN-BOR
20 QUADS 1·4 MM.+ 28 QUADS 0·9 MM.
+ 1 LEAD COVERED QUAD 0·9 MM.

Figure 6—Cross-sections of Czechoslovakian Cables.

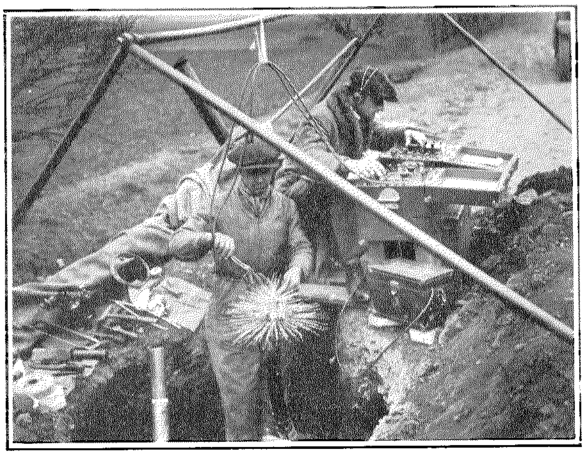


Figure 7—Field Testing.

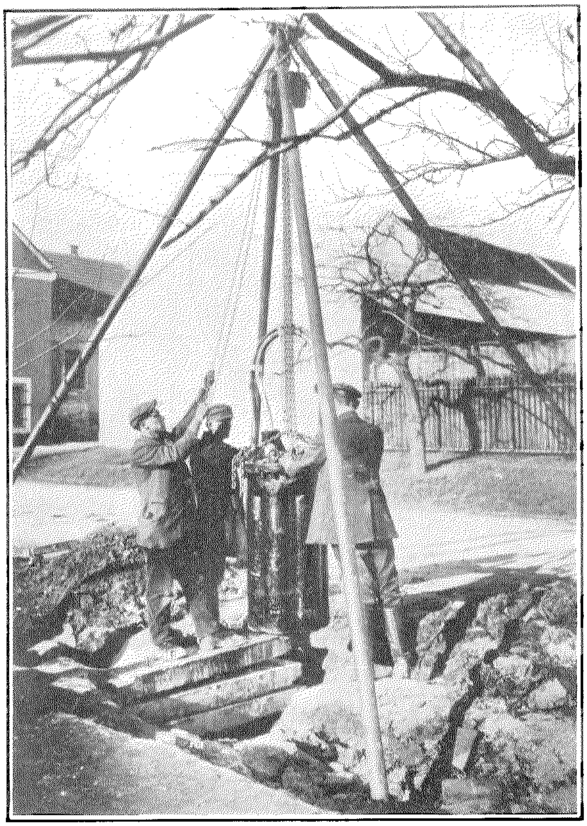


Figure 10—Placing of Loading Coil Case in Manhole.

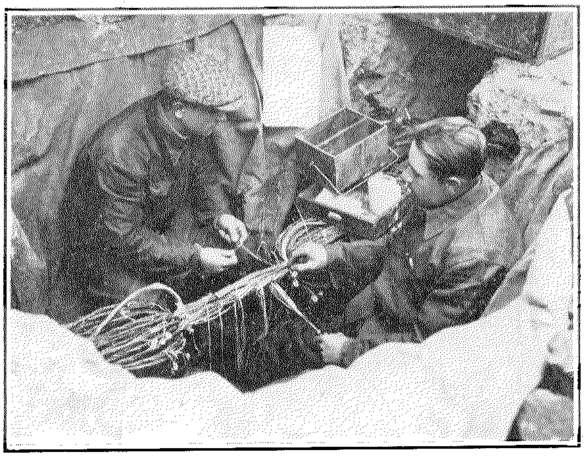


Figure 8—Jointing Work in Progress.

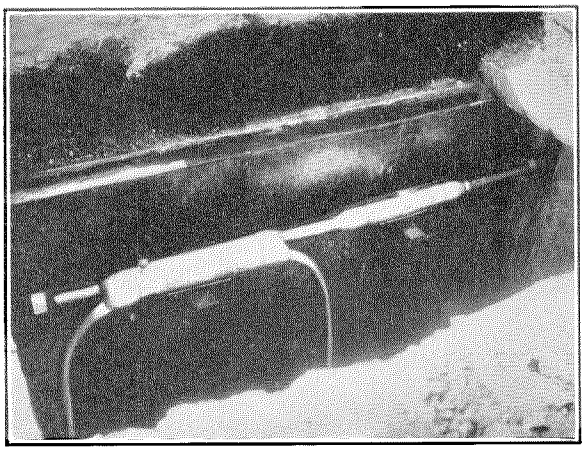


Figure 9—Concrete Loading Coil Manhole.

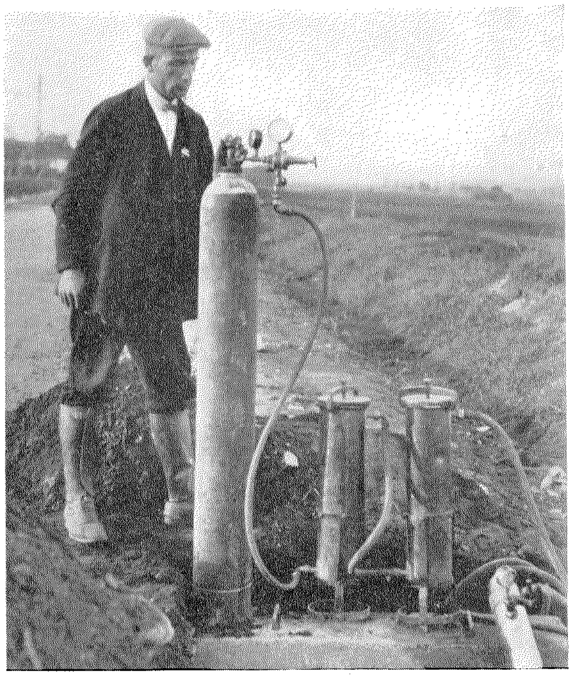


Figure 11—Pressure Testing.

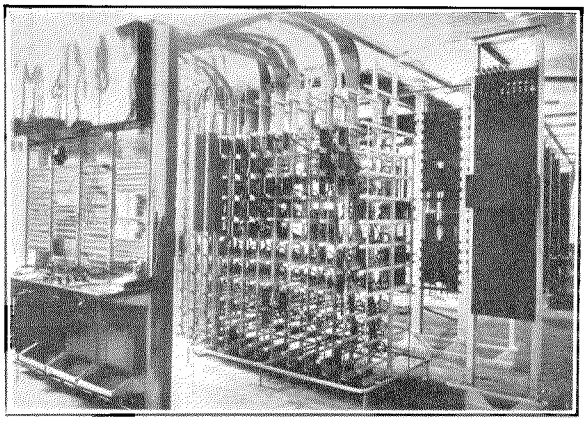


Figure 12—No. 5 Toll Test Board (Kolín).

station in the near future. At all stations an outside power supply is available, and motor-driven generator sets are employed for charging the filament and plate batteries. Duplicate sets of filament, plate and grid batteries are supplied at all stations. The filament battery is operated on a floating routine, and a special noise filter is installed in the battery charging circuit to prevent generator noises entering the toll circuits. The use of the battery floating system makes it possible to obtain closer regulation of the repeater filament voltage, and proves in practice to be far more economical than the charge-discharge system. On the other hand, the plate batteries are operated on the charge-discharge principle, and a separate motor generator is provided for charging purposes. The grid batteries are also operated on the charge-discharge system, and are charged directly from the filament battery through a suitable resistance.

As a provision against the failure of the outside power supply, each station is equipped with an internal combustion engine-generator set using as fuel paraffin or petrol. The plate and filament battery generators are driven directly from this engine.

Duplicate sets of 20-period ringing machines are provided at each station, and in addition, at those stations where the voice frequency ringing circuits terminate, duplicate sets of 500-period voice frequency ringing generators are installed.

Figures 15 and 16 show typical power plant arrangements.

Transmission Tests

As soon as each repeater section had been completed, a series of measurements was made to ascertain whether the cable and loading coils were satisfactory, and whether the required degree of regularity had been obtained. The results of these tests are also of considerable assistance to the transmission engineer during the setting up of the repeatered circuits.

These tests, which include measurements of crosstalk singing point, impedance and attenuation, are discussed briefly.

CROSSTALK

Crosstalk tests were made on each repeater section. Near-end crosstalk was measured from each end of every section, and far-end crosstalk from one end only. The source of tone used was a 20-c test set which provided a complex tone.

Table No. 1 gives a complete summary of

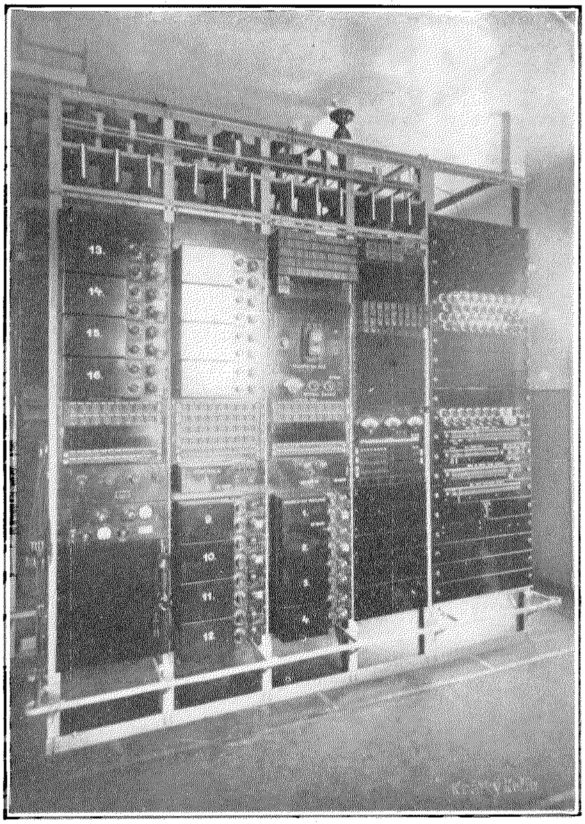


Figure 13—Two-wire Repeater Rack (Kolín).

the results of crosstalk tests made on the Jihlava-Brno repeater section. These results are typical of those obtained throughout the system.

TABLE NO. I.

CROSSTALK SUMMARY JIHLAVA–BRNO CABLE 87.7 Km.

			NEAR END				FAR END			
			AVERAGE		MAXIMUM		AVERAGE		MAXIMUM	
			Cross-talk Units	Nepers	Cross-talk Units	Nepers	Cross-talk Units	Nepers	Cross-talk Units	Nepers
CROSSTALK BETWEEN CIRCUITS IN THE SAME QUAD	2-wire 1.3 mm. H-177-63	PH-S	140	8.9	200	8.5	170	8.7	280	8.2
		S-S	80	9.4	120	9.0	80	9.4	175	8.6
	Separators 0.9 mm. H-177-63	PH-S	120	9.0	150	8.8	70	9.6	95	9.25
		S-S	80	9.4	90	9.3	45	10.0	65	9.6
	4-wire 0.9 mm. H-177-63	PH-S	110	9.1	190	8.6	85	9.4	125	9.0
		S-S	65	9.6	150	8.8	40	10.1	65	9.6
	4-wire 0.9 mm. H-44-25	PH-S	100	9.2	200	8.5	10	11.6	35	10.3
		S-S	50	9.9	80	9.4	5	12.2	20	10.8
CROSSTALK BETWEEN CIRCUITS IN DIFFERENT QUADS IN THE SAME GROUP	2-wire 1.3 mm. H-177-63	PH-PH	95	9.25	200	8.5	90	9.3	250	8.4
		PH-PR	75	9.5	150	8.8	75	9.5	105	9.1
		PR-PR	75	9.5	150	8.8	70	9.6	175	8.6
	Separators 0.9 mm. H-177-63	PH-PH	120	9.0	270	8.2	125	9.0	210	8.5
		PH-PR	95	9.25	180	8.6	40	10.1	60	9.7
		PR-PR	110	9.1	200	8.5	30	10.4	35	10.3
	4-wire 0.9 mm. H-177-63	PH-PH	125	9.0	350	8.0	45	10.0	80	9.4
		PH-PR	70	9.6	130	8.9	45	10.0	60	9.7
		PR-PR	95	9.25	120	9.0	40	10.1	40	10.1
	4-wire 0.9 mm. H-44-25	PH-PH	45	10.0	160	8.7	5	12.2	43	10.0
		PH-PR	35	10.3	80	9.4	5	12.2	20	10.8
		PR-PR	30	10.4	60	9.7	5	12.2	10	11.6
CROSSTALK BETWEEN CIRCUITS IN DIFFERENT GROUPS	1.3 mm. H-177-63 to 0.9 mm. H-44-25	PH-PH	15	11.3	25	10.6	......	......	......	......
		PH-PR	15	11.3	30	10.4	......	......	......	......
		PR-PR	15	11.3	30	10.4	......	......	......	......
	Separators to 0.9 mm. H-44-25 4-wire	PH-PH	30	10.4	100	9.2	10	11.6	45	10.0
		PH-PR	20	10.8	50	9.9	0	..∞..	0	..∞..
		PR-PR	20	10.8	60	9.7	0	..∞..	10	11.6
	0.9 mm. H-177-63 to 0.9 mm. H-44-25*	PH-PH	50	9.9	250	8.4	40	10.1	80	9.4
		PH-PR	45	10.0	110	9.1	15	11.3	25	10.6
		PR-PR	60	9.7	100	9.2	10	11.6	25	10.6

* Four-Wire Medium Heavy to Extra Light in same direction. The crosstalk between four-wire groups in opposite directions was in all cases negligible.

Average Near End crosstalk is average of readings from Jihlava and Brno. The maximum is the maximum observed either in Jihlava or Brno.

SINGING POINT

Three methods of determining the singing point were used. Some circuits were measured by means of the No. 2-A impedance unbalance set, which measures the singing point directly by means of an attenuation measuring circuit at any desired frequency. The majority of the repeater sections were measured by means of the well known "21" test using a calibrated two-wire repeater. On the Bratislava-Hungarian Frontier cable impedance curves were taken on all two-wire 1.3 mm. circuits, and the singing point was calculated from these.

In the singing point tests, the circuit was properly terminated to eliminate reflections from the distant end. Where direct singing point measurements were taken, the line was balanced against a basic network having average characteristics, plus a building-out condenser. The building-out condenser was adjusted to give the best singing point for the circuit under test.

In the case of four-wire H-44-25 circuits, for which no balancing networks are provided, a circuit was chosen at random as a standard, and all similar circuits were measured against it. The impedance curve of the standard circuit was then measured.

From the results of the singing point tests, representative circuits of each type were chosen, and these were measured for impedance frequency characteristics.

Table No. II gives a summary of the values of singing point obtained in a typical repeater section.

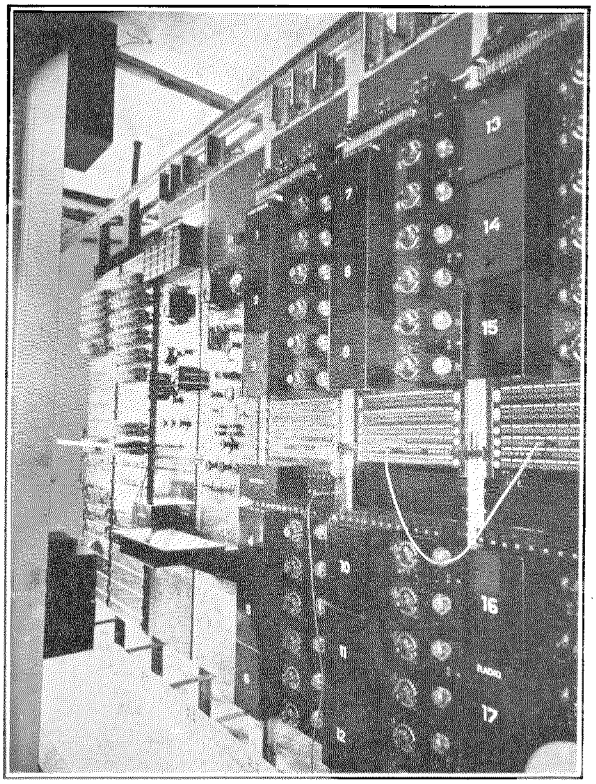


Figure 14—Four-wire Repeater Rack (Jihlava).

IMPEDANCE

As explained under "Singing Point," impedance frequency curves were taken on representative circuits, and these were used to check the results of the direct singing point measurements.

Typical impedance curves are shown in Figures 17 to 22.

ATTENUATION

Measurements of attenuation at 800 and 1,900 periods per second were made on all circuits in

TABLE NO. II.

SINGING POINT SUMMARY REPEATER SECTION BRNO–BŘECLAV

	SINGING POINT (DECIBELS)						
	Measured by 21-test			Calculated from Impedance Curves			
	Average	Maximum	Minimum	Average	Maximum	Minimum	
1.3 mm. H-177-63 Side	26	28	24	26	28	25	From Brno
1.3 mm. H-177-63 Phantom	32	36	28	33	34	28	
0.9 mm. H-177-63 Side	28	. .	26	29	. .	28	
0.9 mm. H-177-63 Phantom	34	38	30	32	36	29	
1.3 mm. H-177-63 Side	27	29	25	27	29	26	From Břeclav
1.3 mm. H-177-63 Phantom	31	33	29	29	29	27	
0.9 mm. H-177-63 Side	27	29	25	. .	26	23	
0.9 mm. H-177-63 Phantom	33	35	29	. .	32	29	

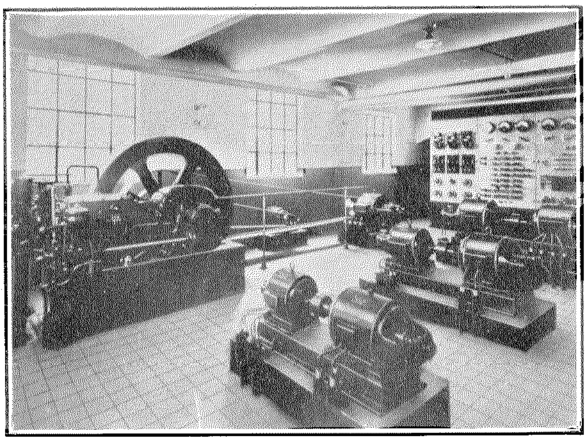


Figure 15—Power Room (Kolín).

each repeater section. Table No. III shows a summary of these measurements.

Attenuation-frequency runs were made on representative circuits of each type. Typical curves are given in Figures 23 to 25.

TABLE NO. III

Average Attenuation Constants at 800 and 1,900 periods per second, and + 15° C.

Average Attenuation at + 15° C.

Type of Circuit	800 periods per sec.		1,900 periods per sec.	
	db/Km.	Neper/Km.	db/Km.	Neper/Km.
1.4 mm. Si.	0.0856	0.00986	0.108	0.0124
H-177-63 Ph.	0.0880	0.0101	0.0995	0.0114
1.3 mm. Si.	0.098	0.0113	0.122	0.0140
H-177-63 Ph.	0.100	0.0115	0.113	0.0130
0.9 mm. Si.	0.176	0.0203	0.198	0.0228
H-177-63 Ph.	0.182	0.0209	0.193	0.0222
0.9 mm. Si.	0.306	0.0352	0.318	0.0366
H-44-25 Ph.	0.253	0.0291	0.265	0.0305

Overall Tests on Repeatered Circuits

All four-wire repeatered circuits, after having been set up for service, were measured for transmission level, overall loss, attenuation-frequency characteristics, and crosstalk.

Two-wire circuits were tested for transmission loss at 300, 800 and 2,000 periods per second, and for crosstalk. Observations of stability were also made on all circuits, as laid down by the C. C. I.

The four-wire circuits so far put into service terminate outside Czechoslovakia, and it is the practice in the neighbouring countries to adjust the circuit to the theoretical overall loss, so that figures of the values obtained are of little interest. In general, the circuits are set up to give an overall loss of 10 db.

Overall attenuation-frequency characteristics on the Czechoslovakian sections are shown for typical four-wire H-44-25 circuits (Figures 26 and 27).

Table IV shows the results of attenuation measurements on typical two-wire H-177-63 circuits.

Broadcasting Circuits

In all repeater sections, other than those between Prague and Brno, special screened broadcasting circuits, either pairs or phantoms, are provided. These circuits have a cut-off frequency of around 9,000 periods per second.

Between Prague and Brno, normal 0.9 mm. H-44-25 circuits have been adapted to broadcasting requirements, as a temporary expedient.

The broadcasting circuit between Brno and Bratislava is also in service. This circuit is arranged so that any one of the three broadcasting stations, Brno, Bratislava, and Vienna, can transmit simultaneously to the other two.

Change-over in the transmission direction in this circuit is necessary as the circuit is of course one way only. This is at present carried out by

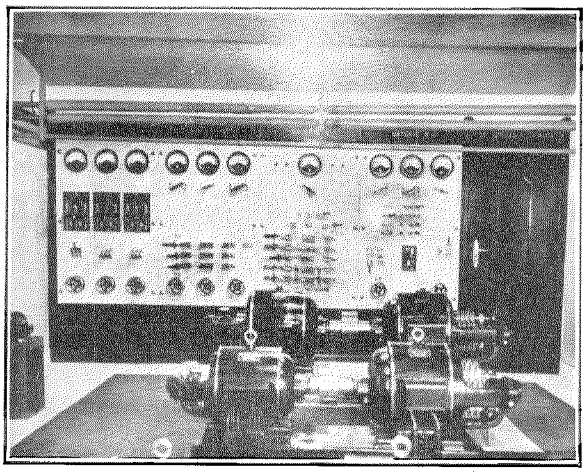


Figure 16—Power Room (Jihlava).

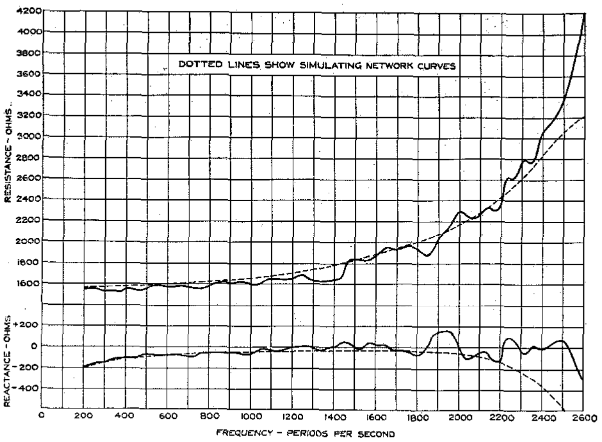


Figure 17—Impedance Curves—1.3 mm. H-177-63 Side Circuit.

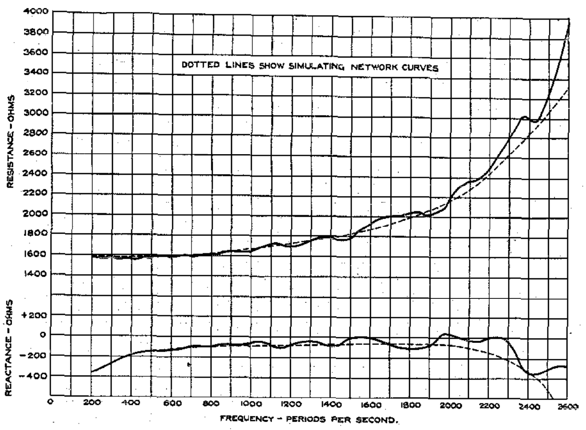


Figure 19—Impedance Curves—0.9 mm. H-177-63 Side Circuit.

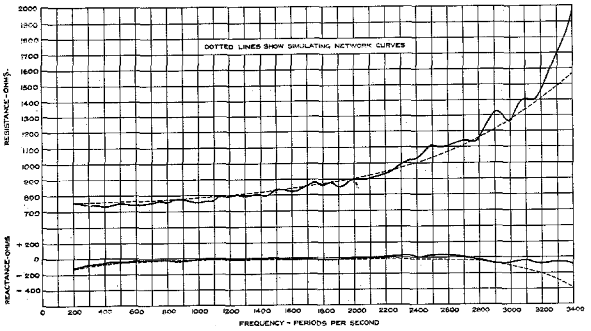


Figure 18—Impedance Curves—1.3 mm. H-177-63 Phantom Circuit.

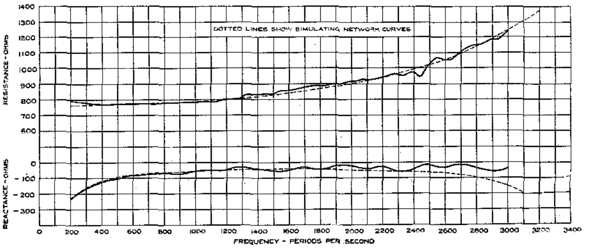


Figure 20—Impedance Curves—0.9 mm. H-177-63 Phantom Circuit.

TABLE NO. IV.

Typical Overall Loss Measurements on Two-Wire Repeatered Circuits

			OVERALL LOSS			
		FREQUENCY PERIODS PER SECOND	E–W		W–E	
	DETAILS OF CIRCUIT		db.	neper	db.	neper
CIRCUITS WITH ONE TWO-WIRE REPEATER	BRNO–VIENNA SIDES 1.3 mm. H-177-63 Brno to Břeclav, 1.4 mm. 2 Km.-190-70 Břeclav to Vienna. Repeatered in Břeclav.	300 500 2000	10.5 9.6 11.6	1.21 1.09 1.34	10.9 9.2 12.6	1.25 1.05 1.45
	Ditto. PHANTOMS.	300 800 2000	10.9 9.1 10.5	1.25 1.04 1.21	10.4 9.2 10.9	1.20 1.05 1.25
CIRCUITS WITH TWO TWO-WIRE REPEATERS	PRAGUE–VIENNA SIDES 1.3 mm. H-177-63 from Prague to Břeclav, 1.4 mm. 2 Km.-190-70 from Břeclav to Vienna. Repeatered in Kolín and Brno.	300 800 2000	9.2 10.4 19.0	1.06 1.20 2.9	9.9 10.8 20.8	1.14 1.24 2.40
CIRCUITS WITH FOUR TWO-WIRE REPEATERS	PRAGUE–BUDAPEST PHANTOMS 1.3 mm. H-177-63. Repeatered in Kolín, Brno, Bratislava and Gyor.	300 800 2000	13.9 10.0 17.1	1.60 1.15 1.97	14.1 10.0 17.6	1.62 1.15 1.97

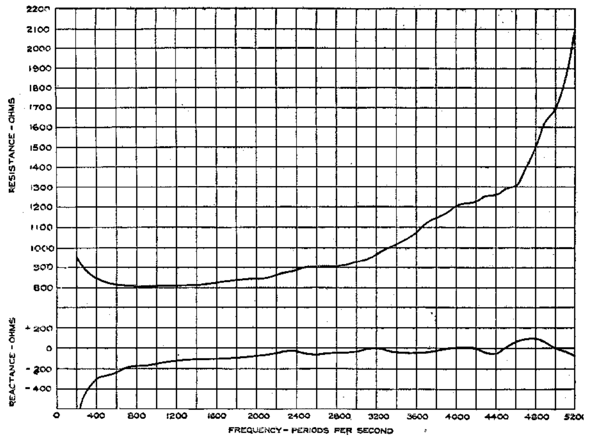


Figure 21—Impedance Curves—0.9 mm. H-44-25 Side Circuit.

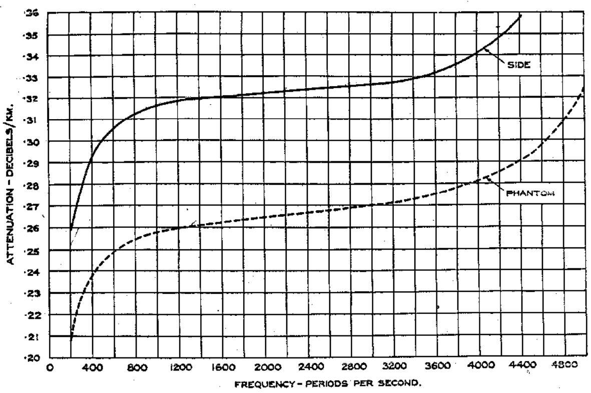


Figure 25—Attenuation-Frequency Curves—0.9 mm. H-44-25 Side and Phantom Circuits.

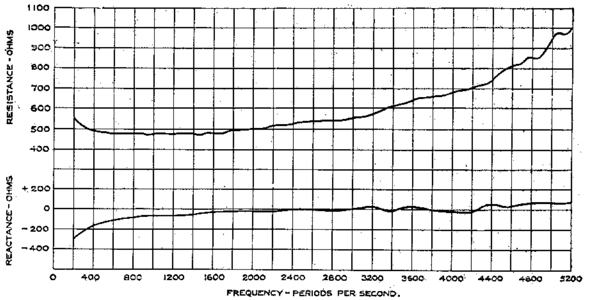


Figure 22—Impedance Curves—0.9 mm. H-44-25 Phantom Circuit.

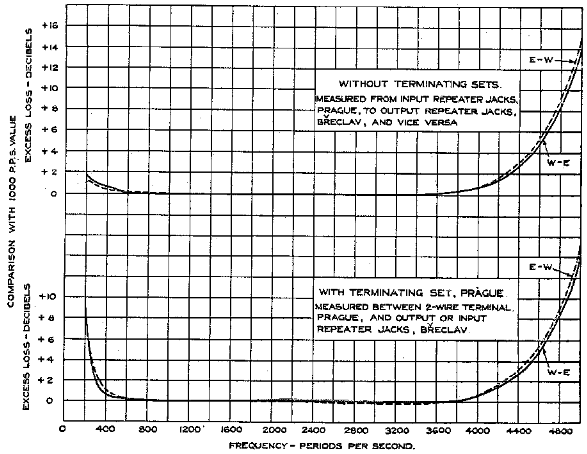


Figure 26—Overall Transmission Frequency Characteristics —0.9 mm. Four-wire H-44-25 Side Circuit.

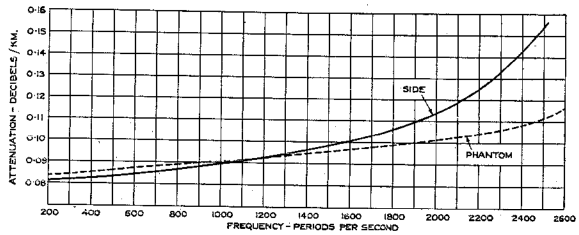


Figure 23—Attenuation-Frequency Curves—1.4 mm. H-177-63 Side and Phantom Circuits.

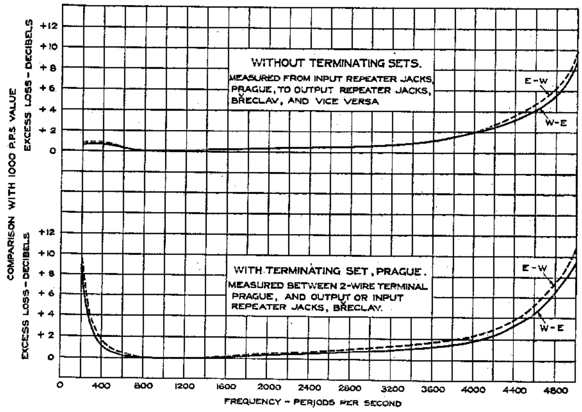


Figure 27—Overall Transmission Frequency Characteristics —0.9 mm. Four-wire H-44-25 Phantom Circuit.

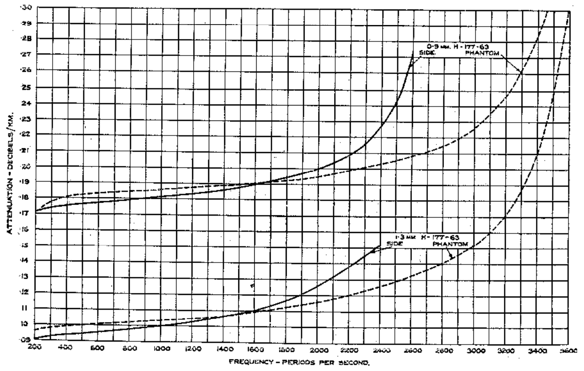


Figure 24—Attenuation-Frequency Curves—1.3 mm. and 0.9 mm. H-177-63 Side and Phantom Circuits.

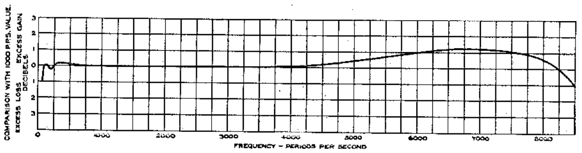


Figure 28—Overall Transmission Frequency Characteristics —Břeclav-Brno Broadcasting Circuit (preliminary set-up).

a three-position manual switching arrangement in each repeater station.

The circuit is equalized so that a substantially flat attenuation-frequency curve is obtained between Brno and Bratislava, independent of the direction of transmission, and at the same time the output to the Vienna branch is also flat.

Arrangements have been made to equalize to Brno and Bratislava with Vienna transmitting, but this change is awaiting the installation of the necessary repeater in Vienna.

Figure 28 shows the results obtained on the first set-up of the broadcasting circuit. These will be improved at the low frequencies later, when equalization will be carried down to 50 periods per second.

A third broadcast circuit, Prague-Berlin, will also be put into service shortly; this is awaiting the equalization of the circuit on German territory.

Conclusion

It is possible in the space available to deal but briefly with such an extensive toll cable network. It is believed, however, that the facts enumerated are sufficient to outline the more important technical features of the Czechoslovakian cable system, and to show that the installation of this network and its associated equipment has placed the long-distance telephone system in Czechoslovakia in the front rank of telephone communication in Europe. Not only has the network furnished an important link in the European international network, but also has made available within the country a most efficient toll system.

Lightning Damage to Toll Cable

DURING the violent thunder-storms with which Europe was visited to an unusual degree in the year 1929, toll cable networks were damaged in isolated instances. Injury occurred at Arlberg in the Tirol, then on the Prag-Kolín, Budapest-Lakihegy and Györ-Magyaróvár cable sections. The last-named case is especially interesting.

The lightning struck a strong acacia tree about 21 km. from Györ, in the direction of Magyaróvár-Vienna, and severed the trunk transversely in two parts. The upper portion was partially buried in the ground and left standing vertically beside the stump of the tree, as illustrated in Figure 1, from which it might be inferred that two trees were involved.

From the trunk, the lightning made its way along the root for about 1 m. under the surface of the ground to the Budapest-Vienna cable, 6 m. distant from the tree and 0.7 m. below the earth's surface. The path of the lightning could be traced through a channel of about 130–200 square millimeters cross section. The earth, notwithstanding the heavy thunder-shower, was almost as dry as dust.

At the place of entrance the lightning had flattened and bent the cable for a length of about 80 cm., as illustrated in Figure 2. About 1.70 m. distant from the entrance section the lead cable sheath had become opened up and partially disintegrated by the heat.

During the repair work, it was noted that the lightning had traveled along the lead sheath for several kilometers and had injured the insulation of the copper conductors nearest the sheath, so that even at about 2 km. from the point where the cable had been struck many broken wires were located.

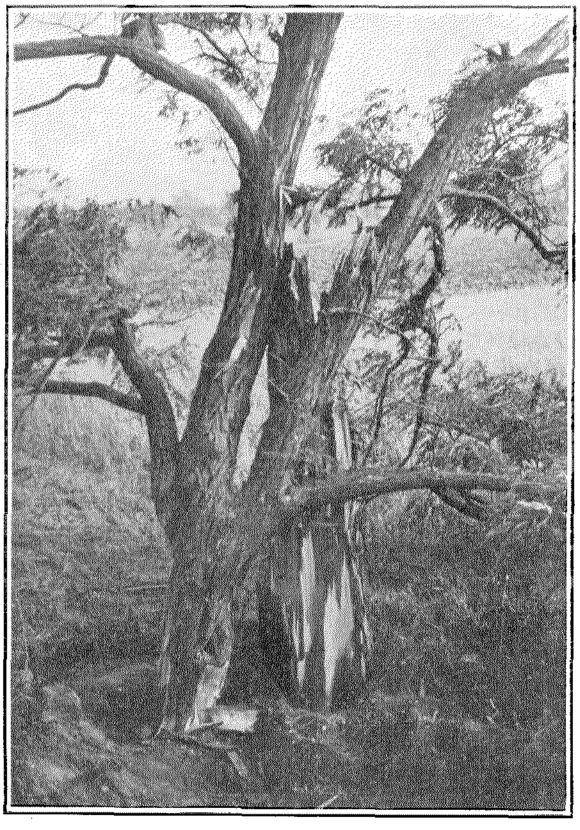


Figure 1—Tree after having been struck by lightning.

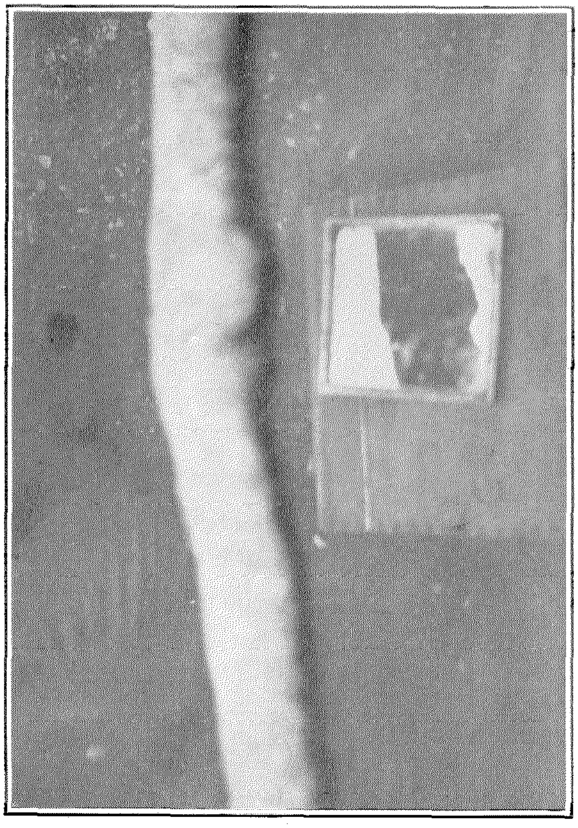


Figure 2—Cable bent and flattened by lightning.

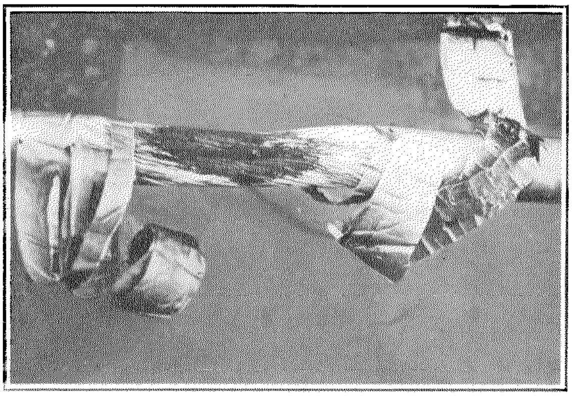


Figure 3—Showing the Appearance of the Cable After the Metal Protective Covering Had Been Removed.

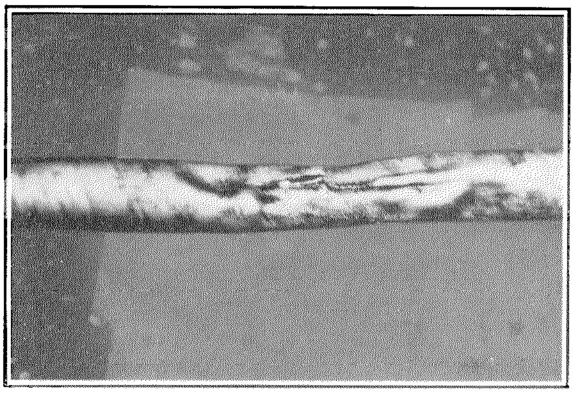


Figure 4—Showing the Cable Core Where the Lightning Struck the Cable.

Notwithstanding the seriousness of the damage done the entire cable was once more in working condition within a time interval of forty-eight hours after the occurrence, thus proving plainly that regardless of the severity of injury to a toll cable from a phenomenon of nature, complete restoration can be effected in minimum time.

The London-Paris-Madrid Telephone Service

By L. G. FREETH

European Engineering Department, International Standard Electric Corporation

UP to the year 1924, when the Compañía Telefónica Nacional de España under concession from the Spanish Government took over the operation of the telephone system in Spain, that country had not been considered by the other European nations for inclusion in the international toll network. At that time long distance telephony in Spain was undeveloped and in fact, almost non-existent. Under the progressive policy of the Compañía Telefónica Nacional de España, the situation was completely altered and it soon became evident that Spain was destined to play an important part in European telephony.

One of the greatest problems which the Spanish Company had to solve was that of providing circuits into the international network. The geographical situation of Spain was such that there was no access to the extensive European toll cable network—this having been designed to interconnect the more heavily populated districts of Western and Central Europe. The only outlet for Spain was through the narrow French-Spanish border, and the only means of communication was over some open-wire lines, leading to Paris via Bordeaux. At this time, these lines were not in sufficiently good condition to permit speech beyond Bordeaux from Madrid, since their maintenance was not up to the highest standard, and crosstalk and the noise induced from neighbouring power lines prevented transmission of normal conversations. Even though the open wires were continuous from the Spanish Border right up to Paris, Paris had no reliable telephone communication with any town south of Bordeaux. At Bordeaux there were one or two cord circuit repeaters of an early type—relics of the Great War—which had been turned over to the French Administration by the American Army, but these repeaters, which were intended for switched communications beyond Bordeaux, were rarely used.

To provide international communication, the Compañía Telefónica Nacional de España (C.T.N.E.) concentrated upon the construction of a first class open wire route from Madrid to the French Border at Hendaye, passing through Zaragoza and San Sebastián. As soon as this was ready, the French Government was asked to provide a through circuit from Paris to a point where their line terminated. The engineers of the French Postes, Télégraphes et Téléphones (P.T.T.) expressed their willingness to co-operate with the C.T.N.E. in an endeavour to establish a circuit between Paris and Madrid. It was soon discovered that an improved condition of the lines and better maintenance routines would be required if success were to be obtained. The International Standard Electric Corporation (I.S.E.C.) was asked to co-operate with the C.T.N.E., to bring about a solution of the problem. A survey of the French lines was made, and based on the results obtained, certain recommendations were laid before the authorities by means of which it was expected to obtain stable and satisfactory transmission. The traffic carried on this line was sufficiently heavy to indicate to the Spanish Telephone Company and to the French Administration that such a circuit, if effectively maintained, would prove to be a sound proposition.

In 1927, the traffic had developed to such an extent that the two Administrations decided to instal a three-channel carrier system between the French capital and Madrid. The route, shown in Figure 1, passes through Versailles, Saumur, Saintes, Bordeaux, San Sebastián and Zaragoza. The carrier terminals were located at Versailles and Zaragoza, the voice-frequency link between Paris and Versailles being provided by means of non-loaded cable circuits, and that between Zaragoza and Madrid by means of open-wire and entrance cable circuits. While this system was being installed, the open wire lines in the French territory were subjected to a close investigation. To improve the already existing communications between Paris and Madrid, which had by that time increased to two physical circuits, the French Government installed two through line repeaters of modern type at Bordeaux. The lines were now so improved between Paris and Madrid, that it was suggested at that time to extend the circuit beyond Paris to London. For this purpose, cord circuit repeaters were installed at Paris. The Paris-Madrid circuits were, as yet, not in perfect condition, and although actual speech tests were carried out between London and Madrid over this switched voice-frequency circuit, it was not actually put into service. It so happened that the carrier system was completed just about the time of these tests, and arrangements were made with the British Post Office and the French Telephone Administration for supplying a direct circuit between London and Madrid, using one of the three carrier channels —the other two channels being used for the Madrid-Paris service. The London channel was extended beyond Paris by means of circuits in the Paris-Boulogne, Boulogne-Canterbury and London-Canterbury cables. The Paris-Boulogne cable was installed in 1926 by the Lignes Télégraphiques et Téléphoniques (L.T.T.), an allied Company of the I.S.E.C. The submarine cable between Boulogne and Canterbury was installed in 1927, and is continuously loaded. The London-Canterbury cable was installed in 1926 by Standard Telephones and Cables Limited.

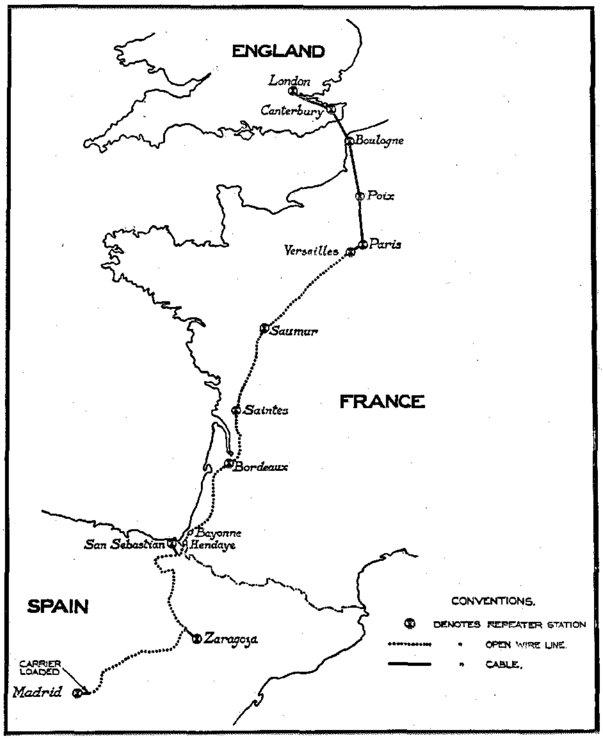


Figure 1—Route of the London-Paris-Madrid Telephone Circuits.

A difficulty in providing a 4-wire circuit between Paris and London was that only 2-wire circuits were available between Paris and Boulogne. It was therefore necessary to select two 2-wire circuits and to arrange for the 2-wire repeaters to operate in one direction only so as to simulate 4-wire working. At this time, the submarine cable circuit was also operated as a 4-wire circuit. Between Paris and Versailles, the link consisted of a 4-wire circuit located in a non-loaded underground cable of a very old type. Since the 1,000 cycle equivalent of this circuit was approximately 15 db, it was decided that in order not to introduce excessive distortion, this circuit should be equalised over the range of transmitted frequencies. For this purpose equalisers were installed at Paris and Versailles, that is to say, at the receiving end of the east and

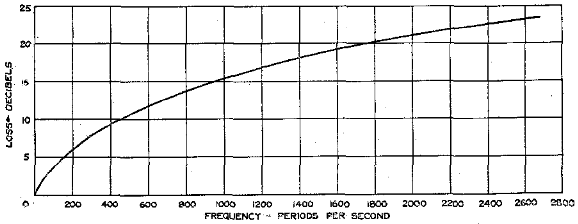


Figure 2— Non-equalised characteristic of the Paris-Versailles link.

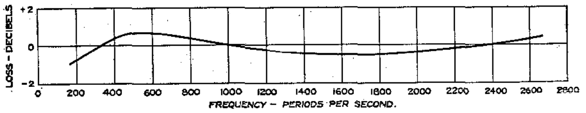


Figure 3—Equalised characteristic of the Paris-Versailles link.

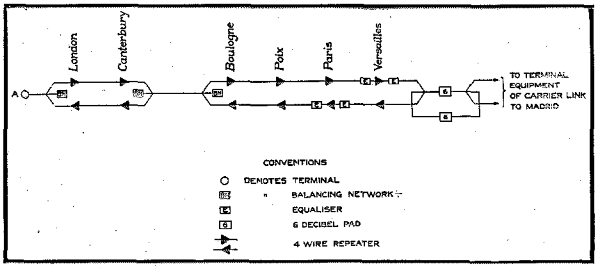


Figure 4—Layout of the London-Versailles audio-frequency circuit.

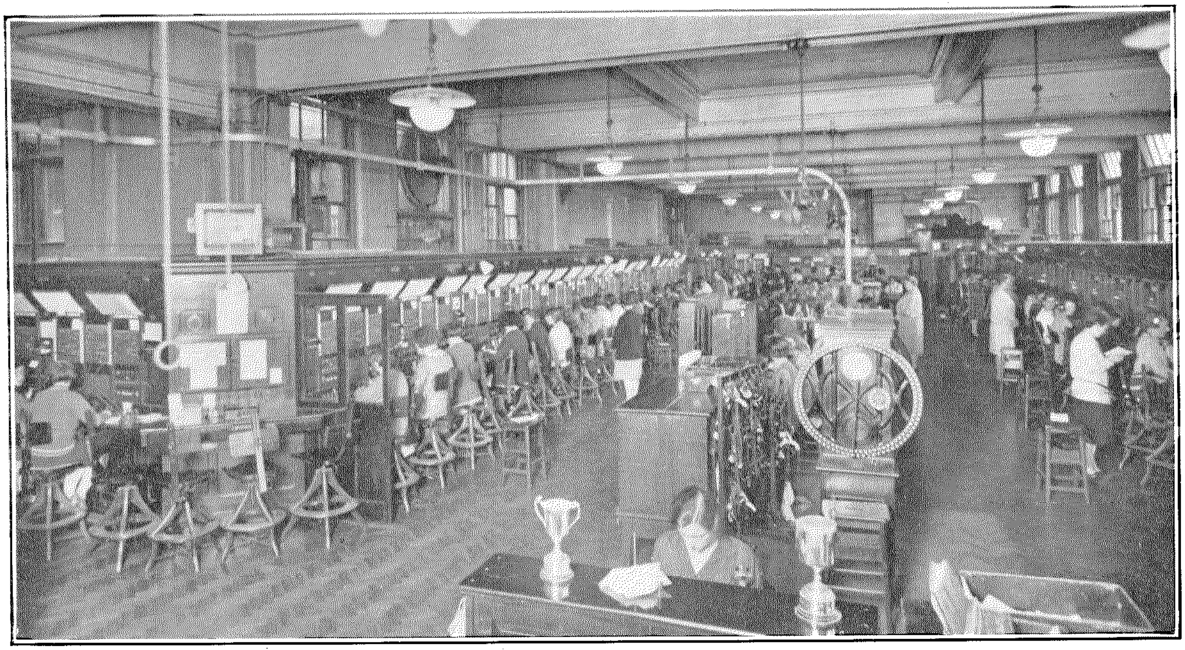


Figure 5—London trunk exchange.

west going circuits. Figures 2 and 3 show typical non-equalised and equalised characteristics of these circuits. At Versailles, the connection was made between the audio and carrier frequency links by connecting the line and network terminals of the terminating set, and of the hybrid coil, through resistance pads having a 6 db loss. In this manner, the use of balancing networks was avoided and a high degree of balance was obtained. The layout of the circuit was now as shown in Figure 4, except that, at that time, continuous 4-wire operation was obtained between Versailles and London.

In Figure 5 is shown the London Trunk Exchange. The location of the London terminal is towards the far end, on the right hand side. In Figures 6, 7 and 8, are shown, respectively, Versailles terminal (carrier and audio-frequency) equipment, Saumur carrier repeater equipment and Zaragoza carrier terminal equipment on the first system.

Other illustrations relating to the line construction are, Figure 9, a section of the line near Bordeaux indicating, on the pole in the foreground, the method of making transpositions, Figure 10, the "guerite," or test hut, at Saintes, and Figure 11, the "guerite" at Thiers, near Bordeaux. From these views, the congested nature of the line at certain points on the route between Paris and Bordeaux can be seen—a condition which will, no doubt, be considerably alleviated by the recent cut-over of the Paris-Bordeaux cable.

The opening of this three channel carrier system demonstrated, not only that it enables additional circuits to be obtained without stringing additional copper circuits, but that it possesses high value in providing satisfactory transmission over lines the condition of which precluded satisfactory voice-frequency telephony.

Not many months passed before it was appreciated that additional circuits would soon be

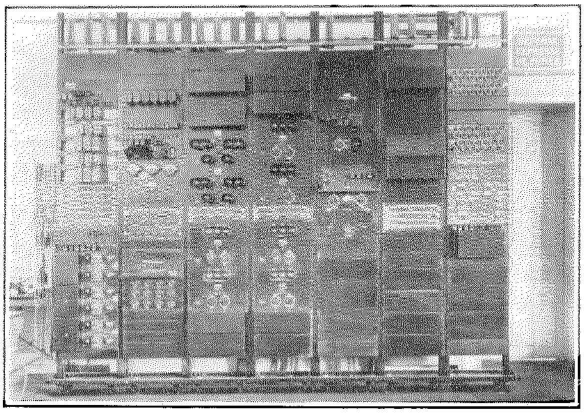


Figure 6—Versailles—1st system terminal.

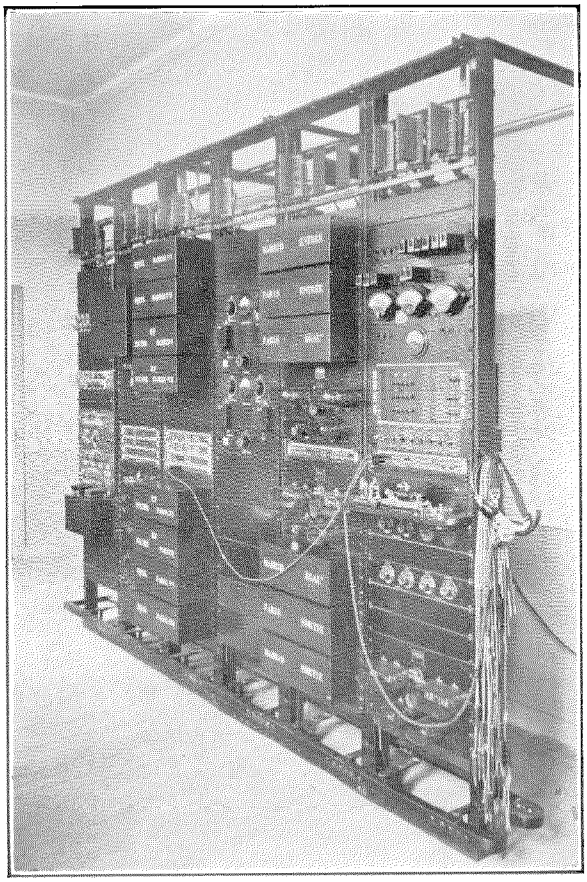
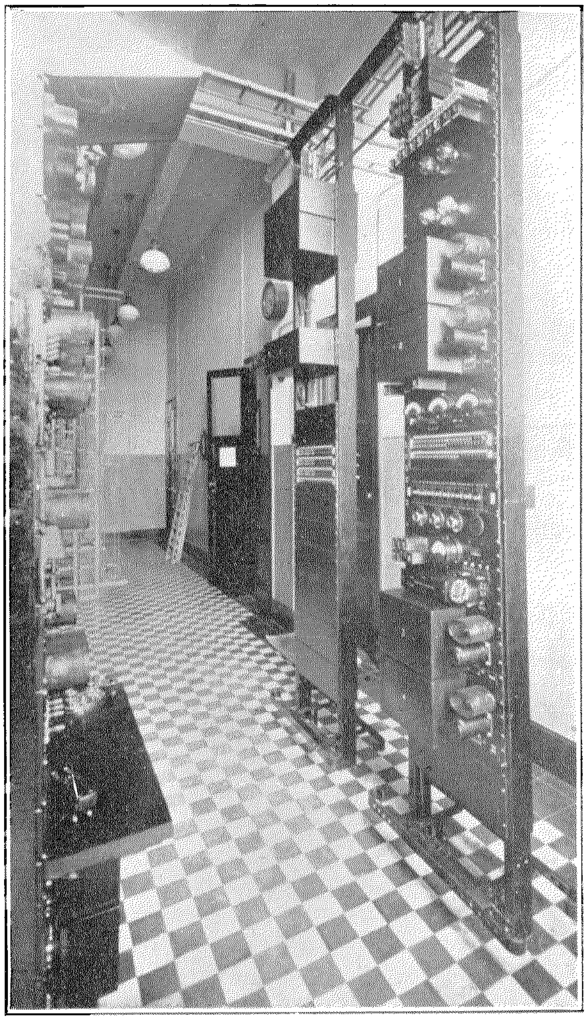


Figure 7—Saumur carrier repeater equipment.

necessary to carry the large increase of traffic. The demand accordingly was made for a second three channel system, and the possibility of providing it was investigated. A survey was made which revealed that, although another pair of wires could be provided between Versailles and the Spanish border, this circuit would require a considerable amount of rebuilding in order to render it suitable for carrier operation. This work consisted in replacing certain short lengths of underground cable by means of open wire lines, the selection of lines on the basis of crosstalk measurements, and the clearing of the route generally from line troubles. The additional channels were brought into Paris from Versailles by means of non-loaded cable circuits reserved for the French Government. These were equalised over the range of transmitted frequencies, as explained above. A 4-wire circuit, similar to that of the first system, was provided in the cable between Paris and Boulogne. Between London and Canterbury there was no difficulty in providing a second 4-wire circuit, similar to that of the first system. For the cross-Channel connection, however, a real difficulty was encountered. Owing to the heavy traffic carried over this link between Great Britain and the Continent, there were no spare circuits available in the submarine cable.

The means chosen for obtaining the additional channel required was that of splitting the 4-wire circuit used for the first London-Madrid circuit into two 2-wire circuits, necessitating the provision at Canterbury and Boulogne of 4-wire terminating sets and balancing networks. The ultimate layout was as shown in Figure 4. There



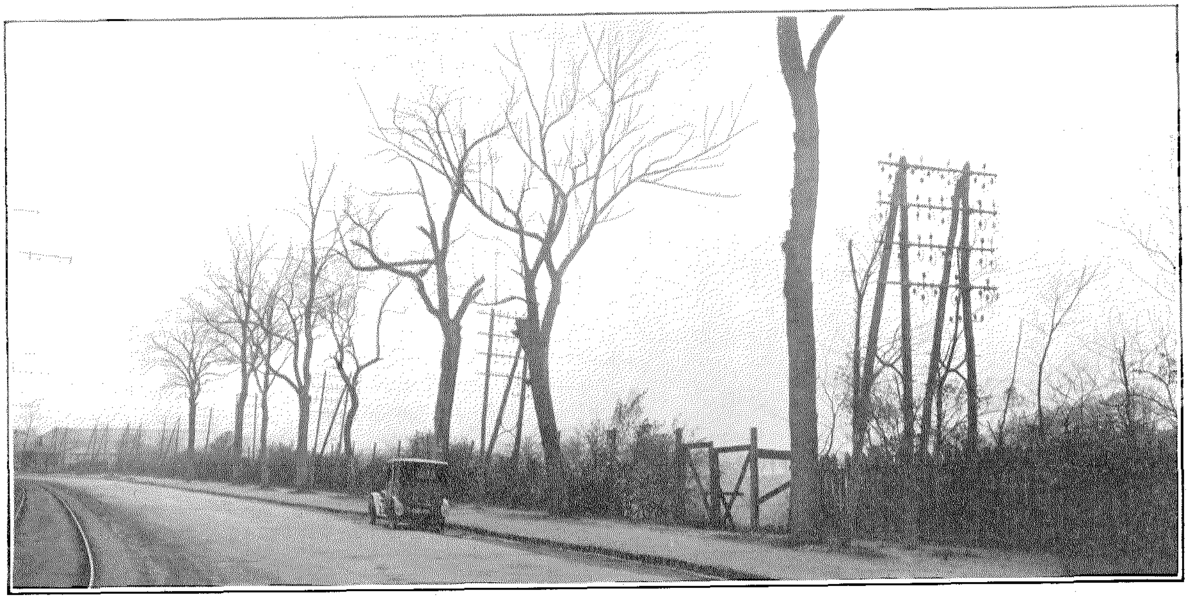


Figure 9—The line near Bordeaux.

was also a circuit shortage between Madrid and the French border; because of this, it was decided to transfer the carrier terminal of the first system from Zaragoza to Madrid, and to employ one of the two circuits rendered spare between Madrid and Zaragoza by this device for the second system. The make-up of the circuits was thus in accordance with the following table:

Section	*Length in km.*	*Type of circuit*
(a) London-Canterbury	99	1.27 mm. 4-wire, medium-heavy loaded, cable circuit.
(b) Canterbury-Boulogne	93	2.01 mm. 2-wire, continuously loaded, submarine cable circuit.
(c) Boulogne-Paris.....	239	1.5 mm. 4-wire, medium-heavy loaded, cable circuit.
(d) Paris-Versailles.....	22	1.0 mm. 4-wire, non-loaded, cable circuit.
(e) Versailles-Madrid...	1412	Carrier link.

The total length of the connection is approximately 1,870 kms. It is made up of not less than four different types of circuits. Referring to Figure 4, it shows that voice-frequency telephone repeaters are located at London, Canterbury, Boulogne, Poix, Paris, Versailles, and from Figure 1 it appears that carrier frequency telephone repeaters are located at Versailles, Saumur, Saintes, Bordeaux, San Sebastián, Zaragoza and Madrid.

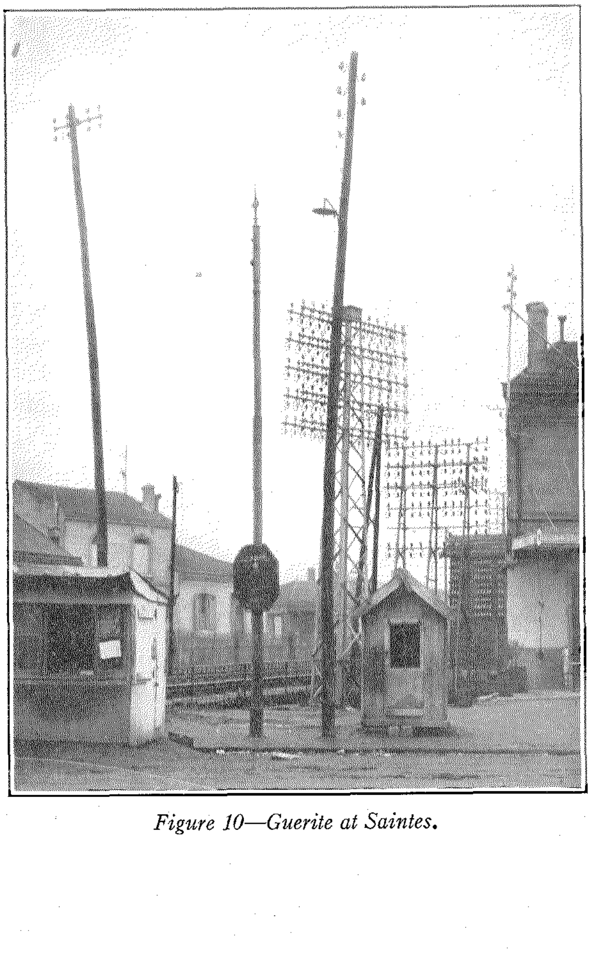


Figure 10—Guerite at Saintes.

Figure 12 indicates that the terminal equipment at Versailles, after the installation of the second system includes, in addition to the carrier terminal equipment, the 4-wire voice-frequency repeaters, equalisers and terminating sets of the cable circuits. It will be noted that each of the two carrier systems is equipped with a pilot regulating and alarm circuit. This precaution was taken owing to the instability of the open-wire lines.

The circuits were set up in such a manner that the loss on the cable circuits between the London terminal and the carrier terminal at Versailles was zero. The overall circuits therefore operated at the net loss value of the carrier frequency link. Figure 13 is the transmission characteristic of the cable circuits between London and Versailles, and Figure 14 that of the overall circuits between London and Madrid.

The second system was cut-over into service on January 1, 1929, there being, therefore, since that time, four circuits between Madrid and Paris, and two between Madrid and London.

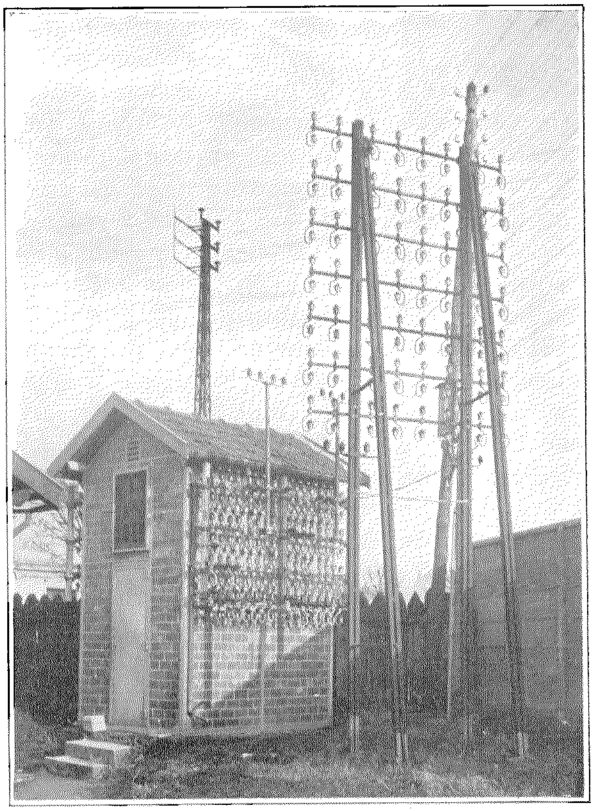


Figure 11—Guerite at Bordeaux.

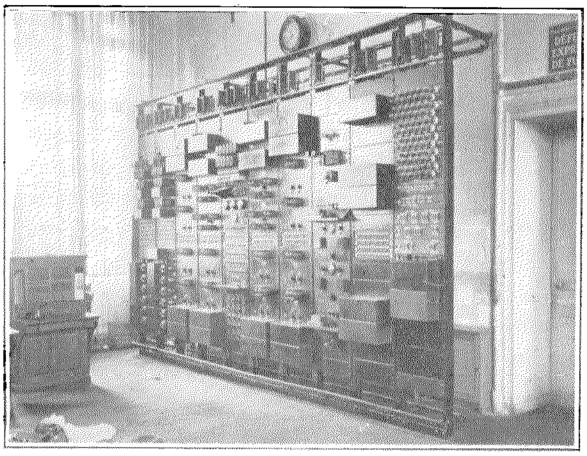


Figure 12—Versailles—1st and 2nd systems terminal.

There are indications that still more circuits will be required in the near future. The difficulty of providing these will be somewhat reduced in view of the recent cut-over of the Paris-Bordeaux cable, which solves the problem of the shortage of circuits over that section of the route. Therefore, by the time this article is in print, the carrier terminal will have been transferred from Versailles to Bordeaux, marking a further stage in the development of the service. There will remain, however, the problem of the shortage of circuits between Bordeaux and San Sebastián; but with the aid of the French Administration, this difficulty should be overcome, until the extension of the Bordeaux cable to the Spanish border—under consideration—is accomplished.

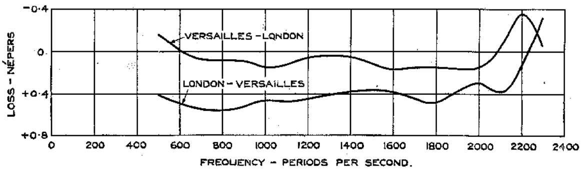


Figure 13—Transmission characteristic of the London-Versailles link.

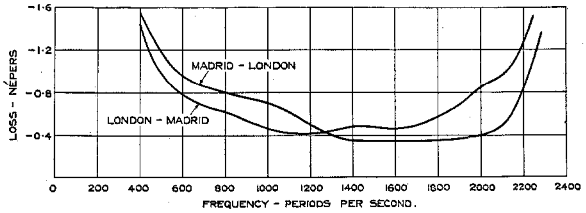


Figure 14—Overall transmission characteristic of the London-Madrid circuits.

Electrical Communication in 1929

WHATEVER else may be said of electrical communication when its history for the year 1929 is finally written, from the viewpoint of progress in long distance telephony it doubtless will be considered outstanding. While this issue of "Electrical Communication" went to press too early to permit obtaining a full picture of the year's happenings in the field of communication throughout the world, the following is a synopsis of most of the important events.

The year 1929 witnessed vigorous growth in the number of short wave radio telephone circuits. Additional short wave channels have been cut into service between the United States and England, making a total of three short wave channels and one long wave channel in operation. At the English end of the link, the equipment for one channel was built by the British Post Office and that for the other channels by Standard Telephones and Cables, Limited. Through cooperation between the American Telephone and Telegraph Company and the British Post Office a transatlantic telephone cable connecting Great Britain and America is also projected.

The North Atlantic radio service was heretofore available to the public only between the hours of 6:30 A. M. and 10:00 P. M., but it is now being furnished on a twenty-four hour basis. A person to person service is also availabe between the United States and England and the seventeen other countries already in telephone connection with Great Britain.

A momentous event occurred on Columbus Day, October 12, when Madrid and Buenos Aires were linked by radio telephone by the International Telephone and Telegraph Corporation. As a result, the International's telephone systems in Argentina and Uruguay, were placed in direct telephone communication with the Spanish Telephone System. The Madrid-Buenos Aires link is the longest of its type in commercial operation, and through the long distance lines of the Compañía Telefónica Nacional de España may connect all the principal countries of Europe with Argentina and Uruguay, and later with Chili. Connection with these South American countries in turn is made possible by reason of the completion in 1928 of the South American transcontinental telephone circuits of the International Telephone and Telegraph Corporation.

The Buenos Aires-Madrid link is especially important in that it represents a radio telephone channel connecting telephone networks to telephone networks as distinguished from "point to point" systems. With the exception of the service between the United States and England, it is the only network to network system in commercial operation in the world today.

During 1929 North Atlantic telephone service was opened between the United States and Czechoslovakia; also extended in Italy by the addition of facilities to Genoa. In Great Britain the transatlantic telephone service was extended to Belfast and Dublin, Ireland, and to the Isle of Man.

The Anglo-Polish service was extended into Poland to Cracow, Lodz, Poznan, and other towns. The Lodz exchange was connected by long distance with the Swiss telephone system. Nine additional departments of France were given telephone service with Switzerland so that the whole of that country, with the exception of Corsica, is now connected with the Swiss network. In addition, telephone communication between Copenhagen, Genoa, Milan, and Turin has been established via Switzerland.

Telephone service between Great Britain and Finland, Paris and Finland, Rome and London, Switzerland and Italy, Hungary and Denmark, and Hungary and Poland is now available. Service between Stockholm and Revel, Esthonia, via Helsingfors, Finland, has also been established.

In September, the new underground Paris-Lyon-Marseilles telephone cable was opened for service. It is 800 km. long and contains 130 circuits. In October, the new Italian underground cable linking Naples with Florence was inaugurated. The year also saw the underground telephone cable between Vienna and Graz extended to the Jugoslavian frontier, as well as the laying of the new East Prussian submarine cable between Leba and Pillau.

Long distance voice frequency dialing was first demonstrated successfully in 1929 on the recently inaugurated Rome to Florence cable.

There was a continued increase in the application of carrier current telephony and telegraphy for the efficient use of existing plants in America, in Europe, especially in Spain, France, and Italy, and in Australasia and in other localities. In Australia and New Zealand notable advance has been made in carrier current communication where the great distances are peculiarly adapted to this type of operation.

In Spain during 1929, the increase in long distance traffic was of the order of 40%, in Chile it was of the order of 60%. In these countries as in all others, long distance traffic has increased rapidly when improved service was furnished. That long distance telephony including international telephony is coming into its own is attested by the fact that in Copenhagen an international telephone directory has been published which generally describes international telephone service, gives information about circuits, details of toll rates and lists some 12,000 firms in 27 countries, classified under various trades and indexed alphabetically.

Experiments in the radio field have been conducted on very long switched radio telephone circuits, notably trials by the American Telephone and Telegraph Company and the British Post Office linking New York with Sydney, Australia, by means of the short wave radio link from New York to London and the British system from London to Australia.

Experimental or commercial "point to point" radio telephony was undertaken in connection with radio telegraph stations, such as Nauen-Buenos Aires and Paris-Buenos Aires.

The British Radio Cable merger went into effect on September 30th. Doubtless this will greatly facilitate the handling of overseas telegraph business.

Long distance commercial radio telephone service between land lines and the S. S. *Leviathan* has recently been announced by the American Telephone and Telegraph Company. Radio telephone experiments were also conducted by the International Telephone and Telegraph Corporation on the S. S. *Berengaria* and the S. S. *Olympic* and it is expected that early in 1930 commercial service will be inaugurated on a number of the larger transatlantic liners.

Technically, important radio and telephone development has been the wide acceptance and general adoption of crystal controlled transmitters. By placing the crystals in temperature ovens the frequency stability of crystal controlled transmitters has been improved so that the frequency band necessary for a given service has been reduced and consequently more stations can be operated in a given width of the radio spectrum.

The year has also seen an increase in the types and numbers of directional radio systems. Most of the important long distance point-to-point radio telephone and telegraph circuits now employ directional antennae at one or both terminals.

Further work has been done on radio telephone secrecy systems. A privacy system is in use on the Madrid-Buenos Aires radio link.

Much research work has been done on radio telephony and telegraphy as applied to aeroplanes. There have been developed radio beacons which indicate to a pilot whether he is on his right course and which show the side of deviation from the course; also a light weight radio telephone transmitter and receiver. The latter equipment permits two way radio telephone communication between planes and the ground for ranges up to about 100 miles.

Broadcasting in 1929 may be said to have reached the trans-oceanic stage. In September, a 500 word speech was transmitted by trans-Atlantic radio telephone and simultaneously broadcast throughout Europe. Other programs were also broadcast across the Atlantic.

The Czechoslovakian Government during the year placed an order for a 120 kw. broadcasting station at Prague. So far as is known, this is the largest station which has been planned up to the present time.

Considerable experimental work has been done on picture transmission and television. Picture transmission systems developed in America, Europe, and Japan are in commercial operation, At more or less regular times certain broadcasting stations send out television transmissions and the Bell Telephone Laboratories have given a demonstration of color television. Satisfactory commercial television, however, still appears to be some distance in the future.

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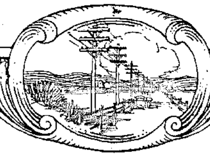

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CONTENTS

INTRODUCTION 207
By G. H. Nash

MADRID–BUENOS AIRES RADIO LINK AND ITS WIRE CONNECTIONS 208
By G. H. Gray and N. K. Fairbank

THE USE OF SHORT WAVES IN RADIO COMMUNICATION 213
By E. M. Deloraine

THE "STANDARD" SHORT WAVE RADIO TRANSMITTERS 216
By C. E. Strong

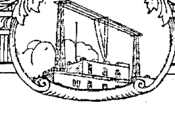
SHORT WAVE RADIO TELEPHONE AND TELEGRAPH RECEIVERS 224
By E. H. Ullrich and R. E. Gray

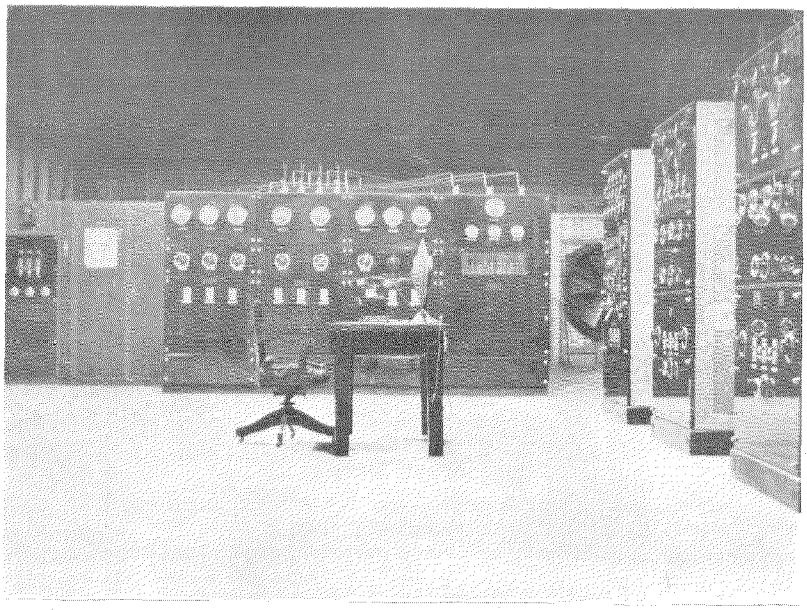
THERMIONIC VACUUM TUBES FOR SHORT WAVES 230
By W. T. Gibson

SHORT WAVE DIRECTIVE TRANSMITTING AND RECEIVING ANTENNAS 235
By E. H. Ullrich and N. K. Fairbank

TERMINAL EQUIPMENTS FOR SHORT WAVE POINT TO POINT RADIO LINKS 242
By F. de Fremery and P. R. Thomas

INAUGURATION OF MADRID–BUENOS AIRES RADIO TELEPHONE LINK 249
By Fred T. Caldwell





Transmitter Room at Madrid, Madrid-Buenos Aires Radio Link

Introduction

By G. H. NASH

Executive Vice President, International Telephone and Telegraph Laboratories, Incorporated

FOR many reasons, the decision of the International Telephone and Telegraph Corporation to establish a short-wave connection between South America and Spain presented problems particularly attractive to those engaged in the provision of such a link. The plans called for connecting subscribers in certain South American telephone operating areas with the great Spanish telephone network and, in addition, through Spain to other European networks. The requirements of the whole project included telephone transmission of a high commercial order for a prescribed number of hours each day, and the provision of equipment capable of connecting at the transmitting end and at the receiving end with two- or four-wire long distance land circuits—the control positions being located at each end of the radio link. Further, it was stipulated that the equipment should be such as to make it difficult for speech to be overheard by those for whom it was not intended. The development was commenced in the Research Laboratories of the International System at a time when little was known regarding shortwave telephony. Consequently, new problems had to be faced in all parts of the equipment, i.e., both in the radio and in the low frequency sections of the undertaking.

The radio path extends from the vicinity of Madrid to the vicinity of Buenos Aires, the distance between the ends of the radio link being about 6,400 miles. This path cuts the meridian at the equator at about 34 degrees. In following thus an oblique line between the Northern and Southern hemispheres, it passes through zones notorious for atmospheric disturbances, and through the equatorial region where radio transmission is particularly subject to fading. Devices for counteracting the effects of fading are accordingly installed, and in addition echo suppressor circuits for preventing the speech from being reflected at the distant ends form an essential part of the equipment.

When the requirements had been ascertained, the design of the equipment was begun in the Research Laboratories. Owing to the special nature of the problem, the Laboratories not only carried out the research work but, together with the manufacturing organisation of the International Telephone and Telegraph Corporation, they were responsible for the construction, installation, and testing of the complete equipment. On the other hand, the operating organisations in Spain and in Argentina undertook the work of designing and constructing the special buildings for the plant and for the attendant staff. They also constructed the directional antenna and the telephone lines for connecting the radio equipment with the telephone networks.

The training of the operating staff—a matter of great importance—was also dealt with by the operating organisations. To provide for commercial service over so vast a stretch of the earth's surface under such novel and exacting conditions, constituted a work of considerable magnitude, and its success is a matter of satisfaction to all who were concerned therewith.

So far as is possible within limited space the particulars contained in this issue of "Electrical Communication" are intended to impart technical and general details concerning a radio link that in many respects introduces a new era in telephonic communication. It is approximately twice the length of the North Atlantic link.

Madrid-Buenos Aires Radio Link and Its Wire Connections

By G. H. GRAY and N. K. FAIRBANK

Engineering Department, International Telephone and Telegraph Corporation

Introduction

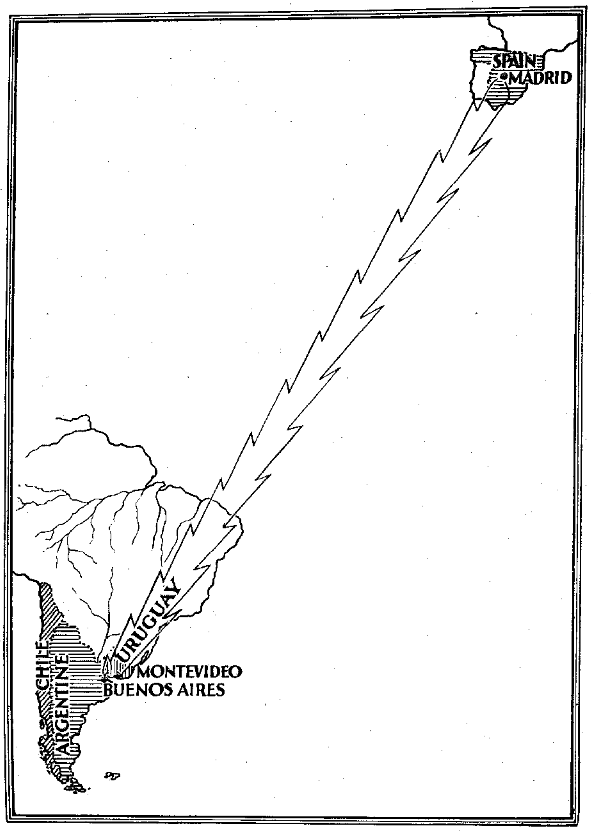
ON October 12th, 1929, the communication facilities of the International System were very greatly extended by the opening for service of a short wave radio telephone link between Madrid, Spain, and Buenos Aires, Argentina. With the opening of this link it has been possible for the first time for the public to talk from their own telephone sets in South America to the Old World. The importance of this channel can hardly be overestimated, since it renders a "network" to "network" service as distinguished from point-to-point service between special booths, and is capable of connecting any telephone in the principal cities of Europe to any telephone in the principal cities of Argentina, Chile, and Uruguay.

Reference to the map shows in part the extensive nature of the telephone systems served by the link. At the South American end, connection is made to 210,000 telephones in the Argentine Republic and 17,000 in Uruguay. At the European end, there are 155,000 telephones in Spain to which the service is available and there are no technical difficulties which prevent this service being extended to those areas in Europe which at present enjoy European International Communication.

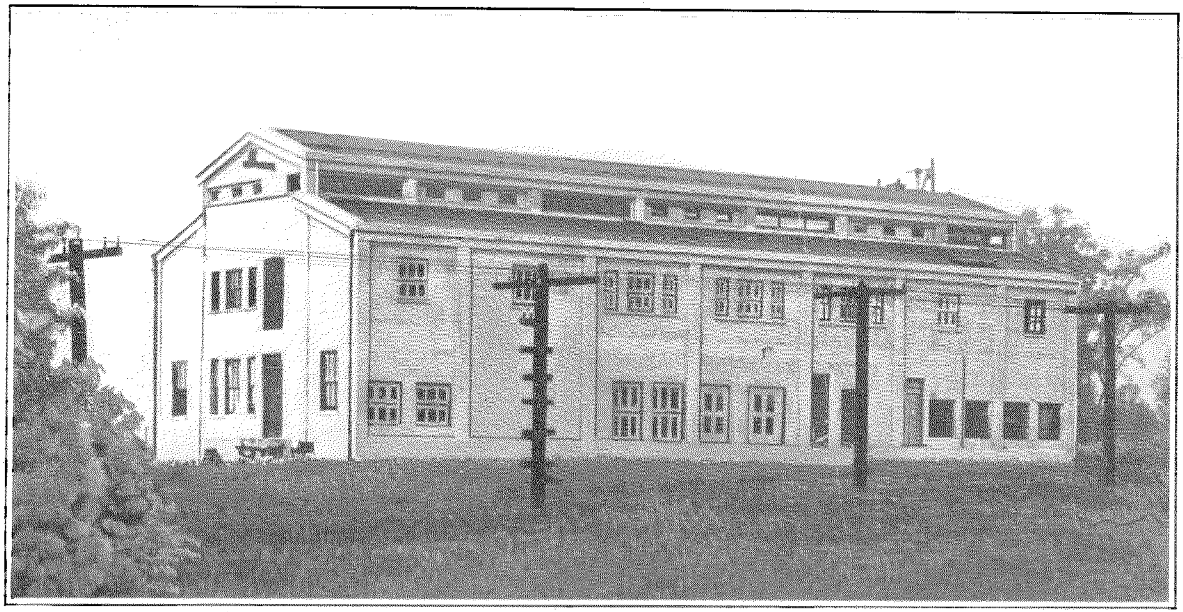
It is of interest to note that the circuit is the second largest area-to-area link in the world, being exceeded in this respect only by the Great Britain-U. S. A. connection. It is, however, by far the longest area-to-area public telephone link in existence, covering approximately 6,400 miles (10,300 Km.) as against the 3,200 miles (5,150 Km.) from England to America, and is provided with a privacy system.

The terminals of the circuit are located at Madrid and Buenos Aires, respectively, and consist, at each end, of a transmitting station and a receiving station situated some distance apart and connected by land lines to the terminal equipment which is situated in the control office. The transmitting station for the Madrid terminal is located at Pozuelo del Rey, about twenty-two miles (thirty-five kilometers) to the east of Madrid, and the receiving station at Grinon, about fifteen miles (twenty-four kilometers) to the south of Madrid. The transmitting and receiving stations for the Buenos Aires terminal are located respectively at Hurlingham and Platanos, each being some twelve miles (twenty kilometers) distant from Buenos Aires.

In order to give reliable service over the entire day, three wavelengths are used at each transmitter. Approximately a fifteen meter wavelength (20,000 Kc.) is employed during the day, a thirty meter wave (10,000 Kc.) at night, while



Spain-South America Radio Telephone Link.



Transmitting Station at Pozuelo del Rey.

a twenty meter wave is required for sunrise and sunset conditions.

A detailed description of the various units comprising the link is given elsewhere in this issue of *Electrical Communication.* The accompanying illustrations give general views of the Madrid and Buenos Aires transmitting and receiving stations.

At the present time traffic on the radio channel is approximately two calls per day and has been as high as nine calls per day.

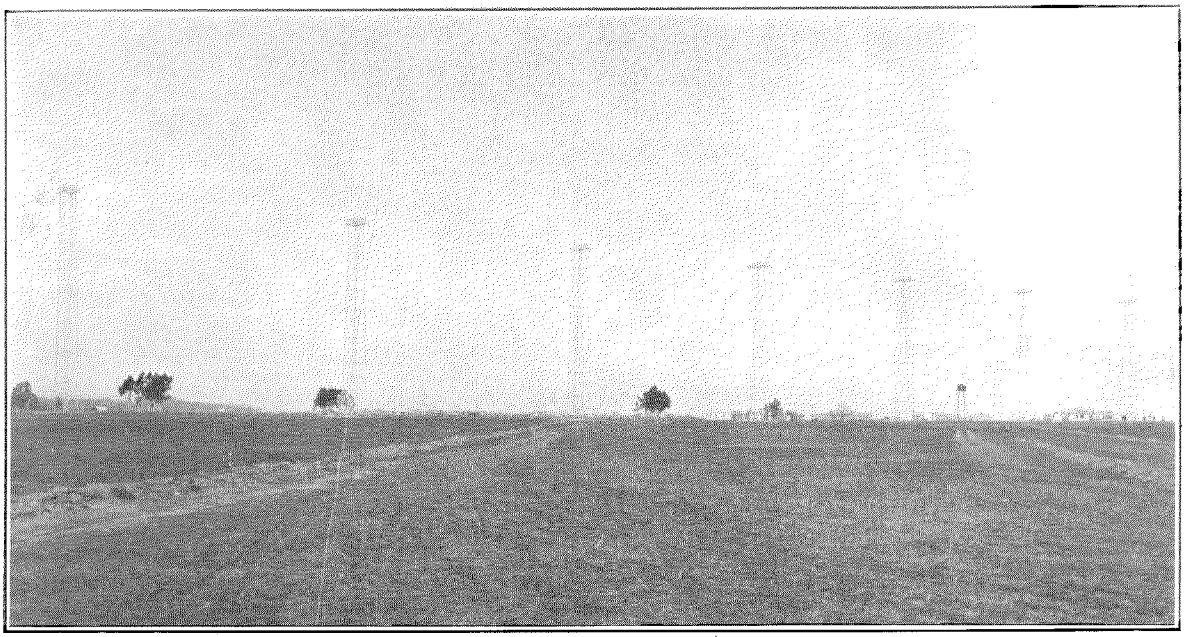
It is proposed in this article to outline briefly the various wire facilities which are used to connect this radio link to the International Telephone Systems in Spain and South America. This will be considered in two parts, the present and the future. It may be stated at the outset that, almost without exception, the wire lines which may be connected with the new radio link are high grade, modern circuits well constructed and well maintained and capable of giving first class service.

At present the service from South America is limited to some of the more important cities in Argentina and to Montevideo, Uruguay. In order to reach these cities, however, it has been necessary to meet and solve a number of new and very interesting problems. For example, it has been necessary to place a cable under one of the widest rivers in the world, and to cross one of the highest mountain ranges in the world where, because of snow storms, train service is completely blocked for certain periods each year. Serious insulation difficulties are also encountered, such, for example, as in parts of Argentina where enormous cobwebs are blown into the circuits by the high winds, thus effectively short circuiting the wires.

Present Circuits

In Argentina, service can be given at present to 83 cities. Direct circuits are available to 15 or more of the important cities, these circuits varying from about fifty kilometers in length to approximately seven hundred kilometers. They consist mostly of copper wire about 2.8 mm. in diameter, which is a little larger than No. 12 N. B. S. Several of these circuits are equipped with through line repeaters. Between Buenos Aires and Bahia Blanca (805 kilometers) a three channel carrier current system is installed, while between Buenos Aires and Rosario (410 kilometers) there are two such systems.

The service to Montevideo is given over a subfluvial cable under the Rio de la Plata from Buenos Aires to Colonia, from which point an



General View of Transmitting Antennas at Buenos Aires.

open wire line takes the circuits into Montevideo. This cable was laid in the early part of 1929 and consists of a twelve quad, sixteen gauge, paper insulated non-loaded cable designed for operation on a four-wire basis. The twelve quad cable will therefore carry twelve simultaneous conversations or eighteen conversations if the phantom circuits are used.

The length of the cable, thirty-seven miles, is so great that it has been necessary to instal repeaters at each end in order to secure satisfactory speech volume. At present the repeater equipment for six circuits is installed, permitting six simultaneous conversations. Plans are under way for increasing the number of circuits in the near future. The cable has been equalised to improve the quality of transmission.

In Spain, connections can be made at Madrid to practically all the more important cities in the country and to many places of lesser importance (2,256 cities in all). The Spanish network consists of upwards of 222,350 kilometers of copper wire, mostly three mm. in diameter (slightly larger than No. 9 A. W. G.); 112 through line repeaters and 43 terminal repeaters are used in connection with this open wire network. Superposed upon these circuits out of Madrid there are 13 three-channel carrier current systems, which add very appreciably to the message carrying capacity of the circuits. In addition, approximately 170 kilometers of toll cable have been placed between Barcelona and Valls. It is expected that this cable will be extended rapidly in the next few years so that Madrid and Barcelona and also Madrid and Irún (near San Sebastián) will be connected by cable.

Circuits are available from Madrid not only to the points mentioned in Spain, but to some other countries as well. For example, there are direct circuits to Lisbon, London, Paris and to other cities in France. At Algeciras, which has a direct circuit from Madrid, connections may be switched over a 24-mile submarine cable to Ceuta, Morocco, thus putting South America into telephonic communication with a third continent.

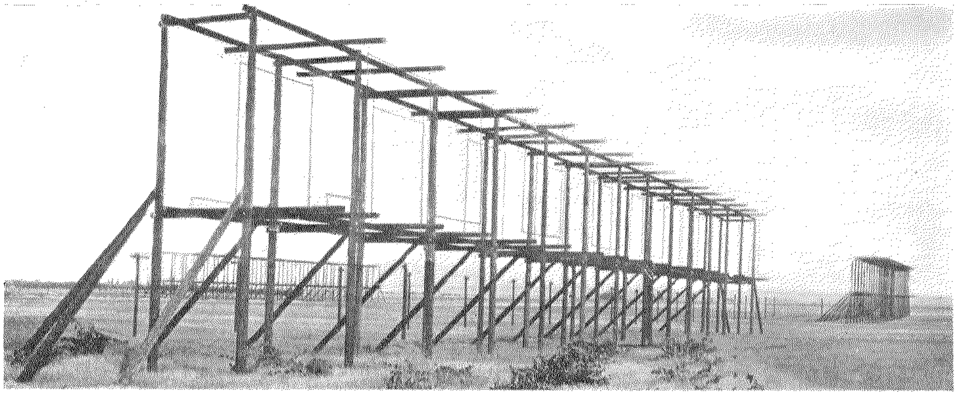
Future Circuits

Connection to 30,000 telephones in Chile will soon be available by compositing the All America telegraph circuits from Buenos Aires to Santiago, a distance of over 1,300 kilometers. The circuit consists mostly of 2.9 mm. (No. 9 A. W. G.)

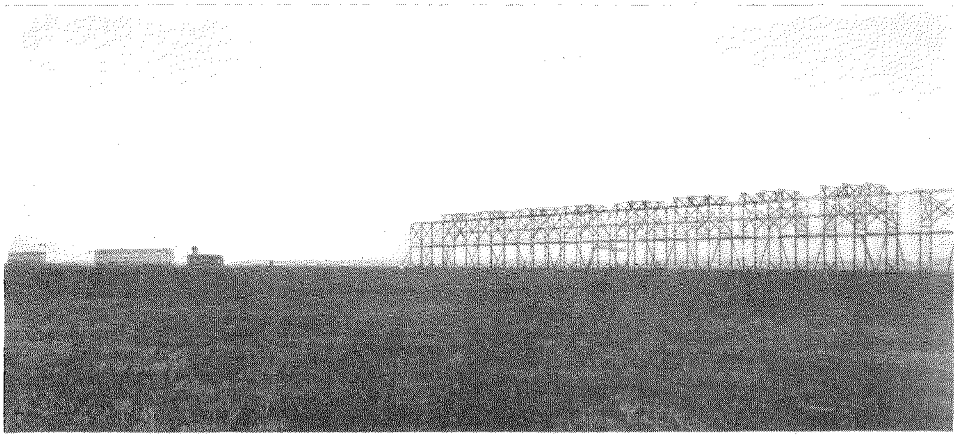
copper, except where cable has been installed over the highest portion of the Andes. The cable section is about sixteen kilometers in length and consists of a buried three quad, thirteen gauge, paper insulated cable with two quads loaded for carrier current circuits. The other quad is loaded for voice frequency only. In some of the more exposed open wire sections, where extra mechanical strength was required, 4.19 mm. (No. 8 B. W. G.) copper has been used instead of the 2.9 mm. wire. Also throughout long stretches a pole has been set between each two existing poles in order to guard against failure of the poles or wire. Superposed upon this circuit from Buenos Aires to Mendoza (about 1,000 kilometers) there is at present a single channel C-2-F carrier current system with one intermediate repeater. This system will be replaced in the near future, however, by a three channel system with three repeaters.

As the European network grows additional points will, of course, come into communication with Madrid and hence with South America.

Work is also under way on a radio link from Madrid to Tenerife, one of the Canary Islands. This island is being connected by a 35-mile



General View of Madrid Receiving Antennas.

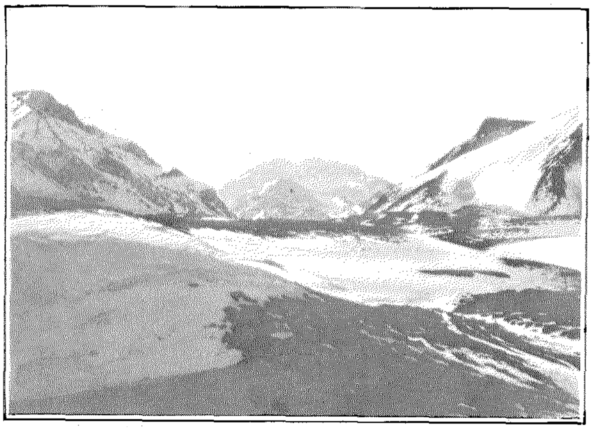


General View of Buenos Aires Receiving Antennas.

submarine cable with Las Palmas on the island of Gran Canaria. The message carrying capacity of this cable will be increased by the installation of carrier current apparatus.

In South America, connections to thirty additional cities in Argentina will be made in the near future. The extensions which are being made to the toll plant in Chile will also add many other cities in this country to the network in the near future.

It is expected that, within two years, a radio link from Buenos Aires to Bogotá will add Colombia to the list of countries which may use the Buenos Aires-Madrid link, and it is entirely possible that similar arrangements may be made for some of the other countries.



Andes Mountains, Showing Country Traversed by South American Transcontinental Line.

The Use of Short Waves in Radio Communication

By E. M. DELORAINE

International Telephone and Telegraph Laboratories, Incorporated

THE rapid expansion in the interchange of knowledge, both commercial and intellectual, involved by modern civilisation, has necessitated an increasingly complete utilisation of the means of communication which science affords. The first attempts at the electrical transmission of sounds were directed towards the possibility of sending electrical impulses along conductors, and from these first experiments wire telegraphy and telephony were developed. From a scientific viewpoint the development of telephony constituted a notable advance over that of telegraphy. A further step was the superposition, particularly upon aerial lines, of several signals, which was accomplished by employing carrier currents modulated by the speech frequencies. Carrier frequencies as high as 30,000 cycles per second were so used, the use of higher frequencies being precluded by the excessive attenuation to which they were subject.

The facilities for long distance communication were still further increased by the discovery that electromagnetic waves having very high frequencies may be propagated through space without the necessity for an intervening conducting circuit. At first, frequencies of the order of 100 kilocycles per second (Kc/s.) were used in this way, but the means then available for producing these waves were such as to encourage the use of the lower frequencies lying between 10 and 100 Kc/s., particularly as these were found to be more suitable for long distance communication. Research in recent years has, however, enabled very much higher frequencies to be used commercially. These, comprising the frequency range from 3,000 to 25,000 Kc/s. (wavelengths from 100 to 12 metres), are known as "short waves," and since it has become possible to overcome the inherent difficulties involved in their use, the study of their properties has shown that by their use not only can the number of available channels of communication be increased, but that in certain cases communication can be effected which could only have been carried out at much greater expense had long waves been employed.

It is usual when speaking of radio waves within the above wide limits of 10 to 25,000 Kc/s. to divide them into three categories, namely, long, medium and short waves. It is hardly necessary, however, to point out that the difference between these is not fundamental, but lies rather in the fact that certain fundamental properties become more or less pronounced as the frequency changes. In consequence of this, radio practice varies considerably in accordance with the type of wave employed.

The longest waves, the frequencies of which lie between 10 and 100 Kc/s. are suitable for long range international telegraphy on account of their reliability, and in spite of the fact that they are liable to interference from atmospheric disturbances. Within this range the waves having frequencies greater than 50 Kc/s. may be used for radio telephone transmissions, the London-New York Transatlantic telephone circuit being the best example of this.

Waves having frequencies between 200 and 2,000 Kc/s. are found to be best adapted for shorter distance transmission, and in particular to broadcasting. The lower end of this range possesses properties similar to those of long waves, being characterised by a comparatively large measure of reliability. With the higher frequencies, on the other hand, new characteristics make their appearance; in particular, considerable diurnal variations in the received field strength.

Finally "short" waves in the range of from 3,000 to 25,000 Kc/s. become more and more suitable for long distance communication as their frequency is increased, in spite of certain irregularities in transmission, the causes of which will be referred to later.

This rapid survey of the properties of electromagnetic waves shows that for the particular case of long distance radio telephony, medium waves are not suitable, but that either the upper or lower ends of the frequency spectrum may be employed.

The differences between the propagation characteristics of short and long waves are explained by assuming that while long waves travel directly from the transmitter to the receiver, short waves received at considerable distances from the transmitter have suffered progressive reflection from a more or less well defined ionised layer in the upper atmosphere. Since the rays have not travelled near the surface of the earth, it is not possible to calculate the received field strength from an empirical formula, as can be done from the Austin-Cohen formula in the case of long waves; and in practice, field strengths may be obtained which are greatly in excess of those predicted by this formula.

A disadvantage experienced in the use of short waves lies in the way in which the received field strength varies in accordance with the time of day, the season of the year, and the distribution of light and darkness over the path of the transmission. The effect of such variations may be greatly reduced by the provision in the receiving system of an automatic volume control which adjusts the amplification in accordance with the strength of the received signal. Even when this is done, however, it is necessary when reliable communication over long periods is desired, to employ several frequencies suitably chosen for each particular case.

Owing to the fact that short waves are much less subject to interference from atmospheric disturbances, a very much higher signal noise ratio is obtained from a given signal strength than would be the case with long wave operation, and it is in consequence possible to work with receiving field strengths which would give signals too weak to be heard above atmospheric noise, were long waves employed.

A very great advantage gained by the use of short waves lies in the way they may be propagated in a predetermined direction in space. In order to obtain directive effects with long wave transmission, cumbersome equipment must be installed, of doubtful efficiency and at a very high cost, due to the fact that the size of the antenna necessary is related to the operating wavelength. For example, in order to obtain an effect similar to that given by a concave mirror with light rays, it is necessary for the aperture of the mirror to be at least equal to twice the wavelength and, in consequence, a prohibitively large antenna network would be required when this is of the order of 5,000 metres.

The directive antennas employed in practice for short waves have a length and height of about 10 and 2 wavelengths, respectively. Such proportions, permissible when the wavelength is of the order of 10 metres, are quite impracticable for waves of the order of hundreds of metres in length.

The use of reflectors and directive antennas has become general in modern short wave practice and considerable progress has been made in their design. The systems at present in use give a gain of the order of 15 decibels over a non-directive system, thus considerably increasing the efficiency of radio communication.

Short wave transmission decreases somewhat the transmitter power necessary to secure communication over long distances, this being largely due to increased efficiency of the antenna on the higher operating frequency. The proportion of the power supplied to the antenna, which is actually radiated, lies between 10% and 15% when the longest waves are employed, and increases to about 70% with waves of the order of 15 metres in length.

Thus, when with very long waves, a power of 300 kw. is taken from the mains, 150 kw. may be supplied to the antenna, and of this, only 17 kw. is radiated, whereas with very short waves, 30 kw. from the mains may give 10 kw. to the antenna, of which 7 kw. is radiated. When account is taken of the fact that the latter power may be concentrated into a restricted angle by means of a directive antenna, the extent to which the short wave system is more efficient can be seen.

By the use of short waves, an enormously increased number of channels of communication is made available, and this constitutes perhaps the greatest gain that has resulted from their use. If the band of frequencies between 50 and 100 Kc/s. is considered, only 25 channels are available, even though the width of each frequency band is reduced to 2,500 cycles—the minimum required for commercial intelligibility—the carrier and one side band suppressed, and no spacing allowed between adjacent bands. Against this, the present state of short wave technique permits the use of 200 telephone channels between 6,000 and 12,000 Kc/s., the spacing between adjacent carrier frequencies being 30 Kc/s. This number would be increased to 600 if the spacing were reduced to 10 Kc/s., a figure which should not be considered impossible of attainment in the light of present progress.

The utilisation of the 13–14 metre waveband, the lower limit of wavelengths used commercially, signifies the availability of about 40 new telephone channels, each occupying 40 Kc/s., a figure which may be soon reduced. Thus an additional metre utilised at the high frequency end of the spectrum gives more telephone channels than are available from the whole of the long waves suitable for long distance work.

The use of directive antenna systems previously mentioned must eventually increase still further the number of channels made available by the use of short waves.

In the consideration of this subject, it must, however, be remembered that in order to provide satisfactory operation over considerable periods it is necessary for one station to employ several wavelengths. This not only reduces the number of channels available, but also increases the cost of installation. Thus, since all new channels are likely to be utilised in the very near future, it is not certain if, in the present state of the art, short waves will be employed to the exclusion of long waves on all long distance circuits, or only for exceptionally long distances.

One of the difficulties experienced in short wave operation is the necessity of maintaining the carrier frequency constant to a much higher degree of precision than is otherwise necessary. This is due to the fact that a given absolute frequency variation becomes a much smaller relative variation as the carrier frequency is increased.

Against this, the band of frequencies occupied by a given type of transmission (telephony for example), represents a much smaller fraction of the carrier frequency in the case of short waves; consequently, the problem of transmitting uniformly a band of frequencies is considerably simplified. When long waves are employed, the tuning of the antenna circuit does not permit the uniform transmission of the band of 2,500 cycles width necessary for telephony, whereas very wide bands can be satisfactorily transmitted on short waves. Due to this fact, aided by progress in receiving technique, one can visualise the simultaneous transmission of many different signals, the realisation of high speed telegraphic transmission, and finally the transmission of special signals requiring a greater band width than telephony.

The foregoing brief discussion shows the complexity of short wave transmission, where any advantage obtained is attended by some corresponding disadvantage. It also shows, however, the extraordinary fertility of this scientific field, and the considerable possibilities which the important advances already realised indicate to be reserved for the future.

The "Standard" Short Wave Radio Transmitters

By C. E. STRONG

International Telephone and Telegraph Laboratories, Incorporated

IN no phase of electrical communication has recent progress been more marked than in radio telephony. The discovery, a few years ago, of the value of short wavelengths for long distance transmission, opened up vastly extended possibilities for linking together the telephone subscribers of different continents. In the realization of a scheme of this kind, the engineer is faced with the problem of attaining in the design and construction of short wave transmitters and receivers the same standards of reliability and grade of service as have become accepted in repeaters and other telephone plant. The trend of modern radio practice in the design of apparatus to fulfill these requirements may be illustrated by a brief description of the short wave transmitting equipment recently developed by the International Telephone and Telegraph Laboratories, Inc.

The transmitter has been designed to include the features for trunk telephone service, intercontinental broadcasting, and high speed telegraphy. It is suitable also for multi-channel telephony, and simultaneous telephony and telegraphy, when used in conjunction with standard types of line carrier telephone and telegraph equipment.

The operating frequencies are of the order for which directional transmission is practicable; and, in general, for point to point service, the equipment is used with a directive antenna concentrating the radiation into a beam pointing in the direction of the receiving station. The power is sufficient to maintain an almost continuous telephone or telegraph service over great distances of the order of ten thousand kilometres.

To maintain continuous service it is necessary to change the operating frequency three or four times in twenty-four hours to suit the transmission conditions corresponding to different states of light and darkness along the trajectory of the waves. The equipment has therefore been designed to be capable of adjustment for operation at any frequency within the band useful for long distance directional transmission, which extends from about 5 to 20 mega-cycles. A special feature is the rapidity with which it is possible to change from one operating frequency to another. The time required is about five minutes.

As regards operating characteristics, special attention has been paid to securing very great frequency stability, freedom from carrier noise, deep modulation for telephony, and clear-cut signals for telegraphy.

In view of the rapid growth of the technique, the design has been made as flexible as possible by adopting low power modulation and a unit form of construction to permit of progressive extension to incorporate new developments. The general appearance of the set is illustrated in Figures 1 and 2 showing respectively the radio units and the power control board.

The power delivered to the antenna when working on continuous wave telegraphy at full load is about 12 kw. at 15 megacycles, being slightly less for the higher frequencies and slightly greater for the lower frequencies.

In telephony, the carrier power and the degree of linear modulation are interdependent, being determined by the limitation that the instantaneous peak power must not exceed 12 kw. As is well known, it is preferable to employ a given carrier-power deeply modulated than a higher power less deeply modulated, with the same peak power in each case, since by the former a better signal-noise ratio is obtained, owing to decrease in the background noise caused by the carrier-wave beating with atmospheric disturbances. The modulator circuits have therefore been designed to permit of 90% to 100% linear modulation. The carrier power must be limited to a quarter of the peak power, that is, to about 3 kw. for 100% linear modulation; but it may be raised to about 4.6 kw. for commercial operation, in which case the slight distortion of the speech peaks when modulating deeper than

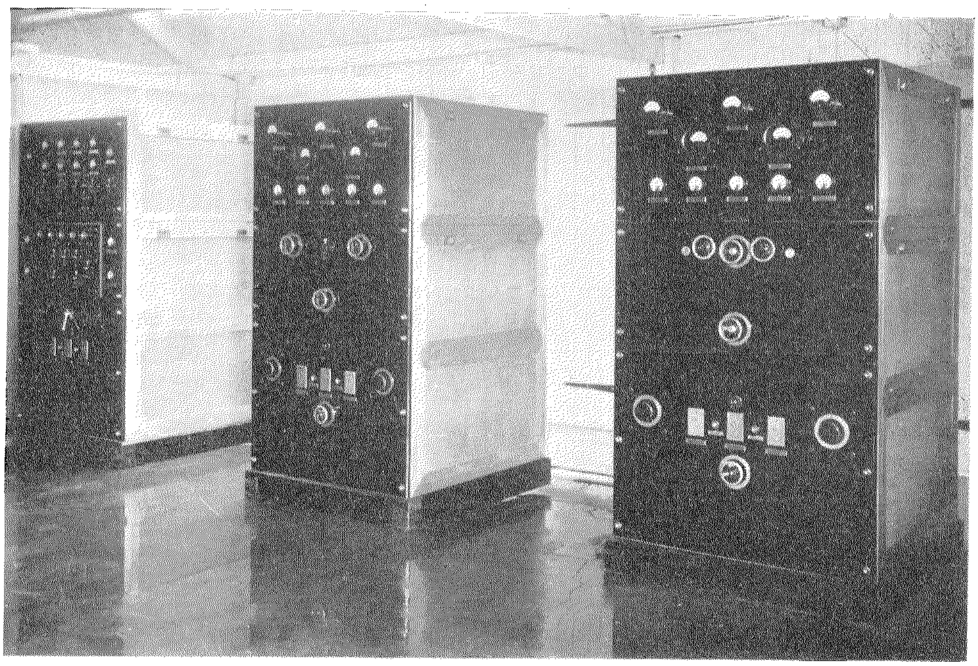


Figure 1—Type III Short Wave Transmitter—Assembly of Transmitter Units.

60%, can be tolerated. For tone modulated telegraphy, the carrier wave power is 4.6 kw. and is fully modulated.

The telegraph speed obtainable for continuous wave telegraphy with well shaped signals is at least 200 words per minute. The power drawn from the mains at full load on telegraphy or telephony is approximately 65 kw.

Very severe requirements are imposed on short-wave transmitters with regard to frequency constancy of the carrier wave, both in respect to dynamic stability, that is, independence of the frequency on keying and modulation, and as regards slow variations caused by changes of temperature or supply voltage, swaying of the antenna, etc. This constancy of frequency is essential, on account of the speech distortion caused by selective fading and interference phenomena which result from an unsteady carrier frequency, and also on account of the close spacing of channels in the short wave band. Stability of frequency during modulation and keying is obtained by the use of a crystal-controlled master-oscillator, balanced coupling stage, and frequency multiplication system. Instability due to antenna sway is prevented by the use of successive highly balanced radio frequency amplifiers.

To obviate slow changes of frequency, the piezo-electric crystal is mounted in a special holder and is kept at a constant temperature by thermostatic control. The general form of the circuit is illustrated in the block diagram (Figure 3).

The master oscillator, operating through a coupling stage, drives a frequency multiplier consisting of two harmonic generators in cascade. The frequency multipliers excite the first of three successive stages of high frequency amplification.

The apparatus for modulation and keying is associated with the first of the three stages of high frequency amplification. Simplified schematics of the modulation and keying circuits

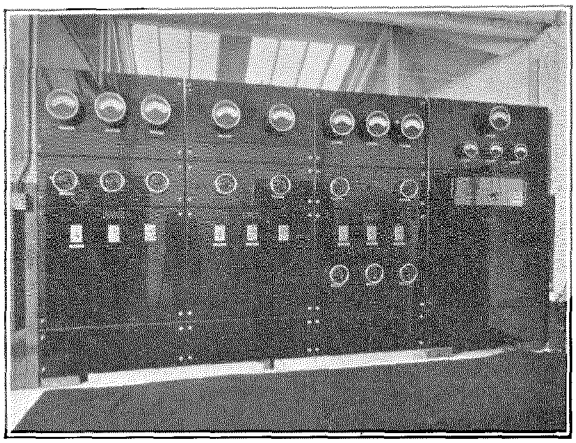


Figure 2—Type III Short Wave Transmitter—View of Power Board.

are shown in Figures 4 and 5. The system is one of low power modulation and keying, with subsequent amplification of the modulated or interrupted carrier wave. The purpose of the frequency multipliers is to lower the frequency of the master oscillator to a value at which quartz crystal control can be satisfactorily applied.

Low power modulation has been adopted as it has the same advantages over high power modulation in a short wave equipment as have been found in the case of broadcasting transmitters. In addition the low power system seems more promising at present from the point of view of providing for new developments.

The transmitter has four pairs of input lines. Two pairs are for "main line" telegraph and telephone, and the remaining two are for "local test" telegraph and telephone. A key on the set switches over the modulator input and keying relay from the "main line" pairs to "local test" pairs. The change over from telephone to telegraph adjustment is by means of relays controlled by one key.

From Figure 3 it may be seen that the apparatus divides up into three main sections, i. e., (1) the apparatus for generating the constant frequency carrier at low power and for modulating and keying; (2) the first stage of power amplification; (3) the second stage of power amplification. In the assembly of the apparatus it was found convenient from many points of view to adopt the unit form of construction, each of the three main sections of the system being comprised in one unit. Figure 1 shows the three radio units. The unit on the left comprises

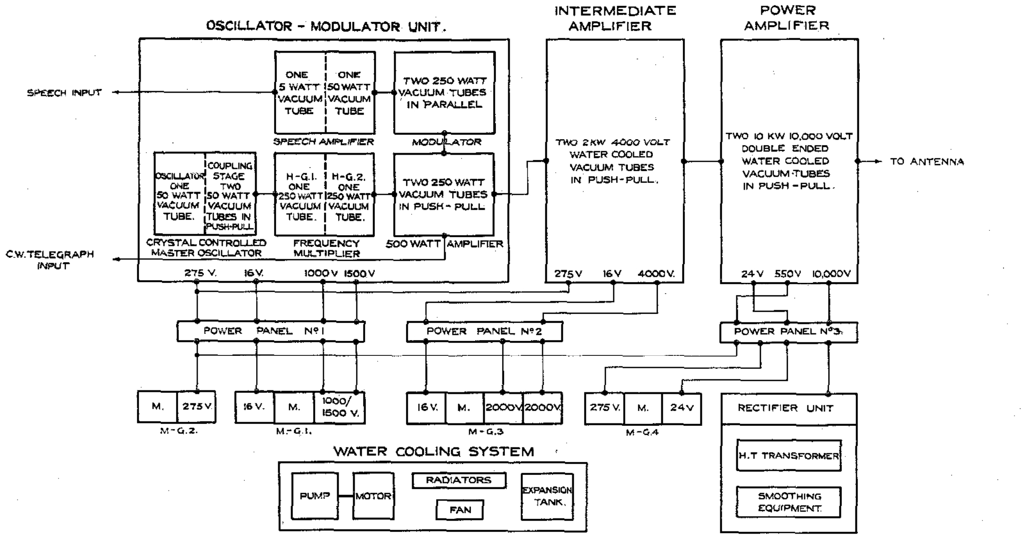


Figure 3—Type III Short Wave Transmitter—Block Schematic.

the carrier-generating, modulating, and keying apparatus, and is referred to as the Oscillator-Modulator unit. The unit in the centre is the intermediate amplifier, being the first stage of amplification after the modulated amplifier. The unit on the right is the power amplifier.

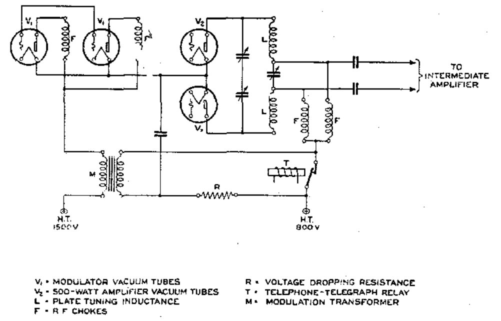

V₁
V₁
V₂
V₂
F
F
L
L
F
F
TO INTERMEDIATE AMPLIFIER
M
T
R
H.T. 1500 V
H.T. 800 V
V₁ = MODULATOR VACUUM TUBES
V₂ = 500-WATT AMPLIFIER VACUUM TUBES
L = PLATE TUNING INDUCTANCE
F = R F CHOKES
R = VOLTAGE DROPPING RESISTANCE
T = TELEPHONE-TELEGRAPH RELAY
M = MODULATION TRANSFORMER

Figure 4—Simplified Schematic of Modulation Circuit.

Each of the three radio units has its own distinct panel in the power control board, and separate power plant.

For telephone operation, provision is made for monitoring with head phones at the output of each unit, to enable any wrong adjustment causing distortion to be very easily localised.

Among the advantages of the unit form of construction may be cited improved accessibility, flexibility for increase or reduction of power, flexibility for interchange of units in stations comprising more than one equipment, simplification of the problem of symmetrical distribution of apparatus, and certain advantages in circuit design including good shielding between stages and elimination of ground return currents between stages causing instability and carrier noise.

The improvement in accessibility arises from the fact that advantage has been taken of the possibility of separating the amplifying stages some distance from each other and connecting them together by transmission lines so that each amplifier—which must in itself be very compact to keep certain of the connections very short—can be made accessible from all sides.

The flexibility, above referred to, for increasing or decreasing the power renders it possible to work into the antenna either from the Oscillator-Modulator unit alone (the other two stages being switched off entirely) or from the output of the intermediate amplifier, or lastly in the usual way from the power amplifier. By duplicating the oscillator-modulator, together with its associated power plant, a high degree of security against total failure of the service is obtained.

The units are coupled together by means of short transmission lines. Precautions are taken to obtain series feed current in the lines only, thus avoiding parallel line current returning from one unit to another through earth. The methods adopted have resulted in remarkable freedom from reaction between units, in freedom from stray earth currents, and in equality of the drives and impedance conditions for the valves on opposite sides of the balanced amplifiers.

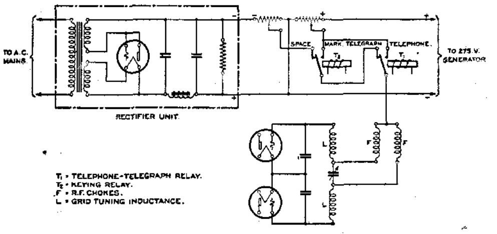


Figure 5—Simplified Schematic of Keying Circuit.

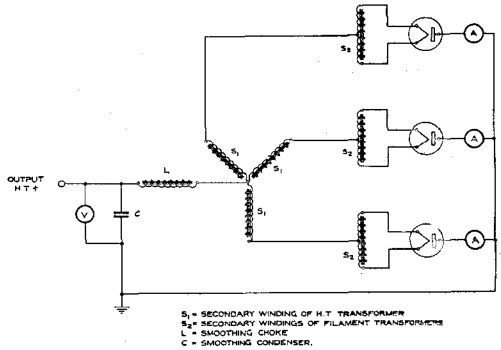

S₂
S₂
S₂
S₁
S₁
S₁
L
C
V
A
A
A
OUTPUT H T +
S₁ = SECONDARY WINDING OF H.T TRANSFORMER
S₂ = SECONDARY WINDINGS OF FILAMENT TRANSFORMERS
L = SMOOTHING CHOKE
C = SMOOTHING CONDENSER.

Figure 6—Simplified Schematic of H. T. Rectifier Circuit.

The units are built on frameworks of duralumin angle and are enclosed at the sides and backs by doors comprising frames of the same material covered by perforated aluminium sheeting. The front panels are of polished slate shielded on the inside by metal sheets. The units are each 6 feet 6 inches high (about 198 cm.), 3 feet 8 inches wide (about 112 cm.), 4 feet deep (about 122 cm.).

The transmission lines forming the connections between units are carried on insulators mounted on the tops of the units, and are insulated from direct current by stopping condensers within the units. The power plant associated with and included in the equipment comprises four motor generator sets, a 10,000 volt rectifier (see Figure 6), and the power control board. The standard equipment is designed for operation from a 3 phase 50-60 cycle supply at a voltage between phases of either 220 or 415 as required.

The four motor generator sets provide the filament and grid voltages for all the valves, excitation of control circuits, and high tension plate supplies for the oscillator-modulator and the intermediate amplifier. The 10,000 volt rectifier supplies only the plates of the power amplifier.

A power panel is provided for each transmitter unit, and controls the power plant associated with that unit. The three power panels are lined up with the front panel of the rectifier to form one power board, as in Figure 2. The panels are of polished slate and are mounted on angle iron frameworks. Each power panel is 6 feet 6 inches high (about 198 cm.), and 2 feet 6 inches wide (about 76 cm.). The rectifier panel is 6 feet 6 inches high, and 3 feet 8 inches wide (about 112 cm.). The power board forms the front of an enclosure in which are located the H. T. transformer and the smoothing apparatus of the rectifier system.

The valves used in the Intermediate and Power Amplifiers are water-cooled, and a water-cooling system is included in the equipment. This system consists of a circulating pump, a small expansion tank, and an air blast cooler.

The Oscillator-Modulator unit with its associated motor-generators and power panel forms a complete low power transmitter known as the Type 1 transmitter. It delivers about 300 watts to the antenna for continuous wave telegraphy, and 200 watts for telephony. By the addition of the Intermediate Amplifier, with its associated motor-generator and power panel, and the water-cooling system, the Type II transmitter is formed which is capable of delivering to the antenna about 3 kw. for telegraphy and 0.83 kw. for telephony. These telephony powers are based on 100% modulation. Finally the Type III set, herein described, is made up by the addition to the Type II equipment of the Power Amplifier with its associated power panel, machine, and rectifier. It will be seen that a Type I or Type II equipment may therefore be easily extended if it is desired to raise the power of the installation.

The equipment is started up or stopped, and all potentials are applied by means of push-buttons situated on the Power Board and duplicated on the front panels of the units. Control circuits are arranged in such a manner that it is impossible to start up the transmitter in a way liable to cause damage. No high tension voltages can be applied, for example, until the grid and filament voltages are at their proper levels.

The equipment is adequately protected by fuses, according to standard practices; other security provisions include overload relays in the high tension plate supplies, water flow devices to remove plate and filament voltages in case of failure of the water flow, water tem-

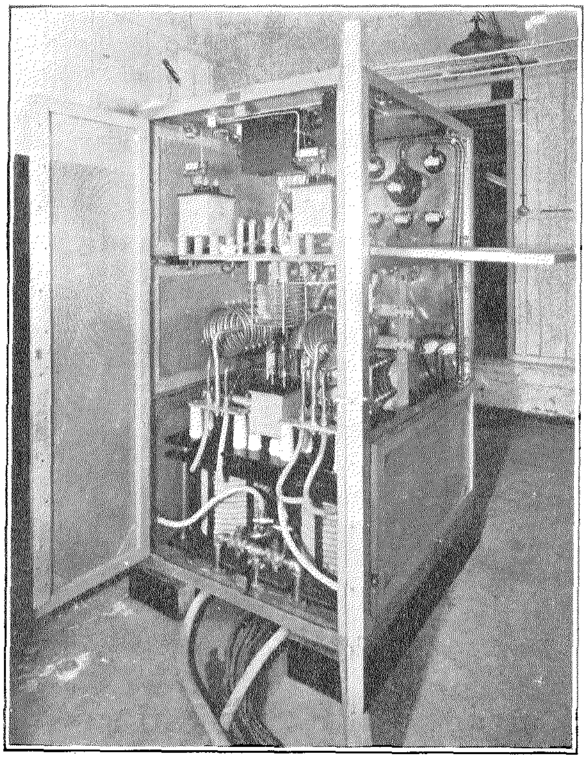


Figure 7—Rear View of Power Amplifier.

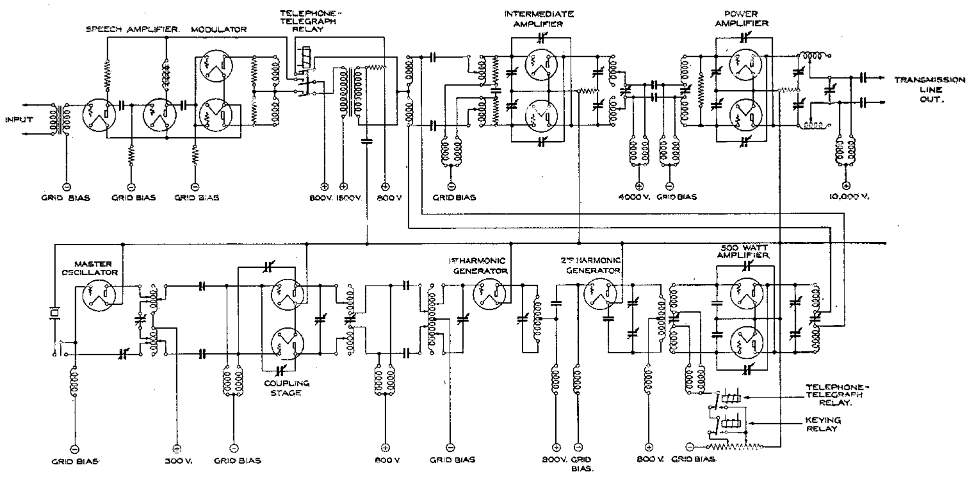


Figure 8—Type III Short Wave Transmitter. Simplified Circuit Schematic.

perature alarms, and gate switches on all high tension enclosures, including the radio units themselves.

The mechanical design of the higher powered radio units presented a difficult problem. It was necessary to preserve close symmetry, to keep certain leads short and yet to allow ample spacing to avoid flash over (which occurs very easily on the higher frequencies in the range), to provide for extreme rigidity, and lastly to use insulating materials sparingly in high frequency fields and only material of low dielectric loss. An idea of the construction adopted may be gathered from Figure 7.

The general form of the circuit of the transmitter given in the block diagram (Figure 3) is shown in greater detail in the simplified circuit of Figure 8.

The master oscillator employs a special 50-watt valve of high amplification-factor operated with the plate voltage reduced to 300. The oscillator may work as a self-excited oscillator or as a crystal controlled oscillator, according to the position of the switch in the grid circuit.

The crystals for the different operating frequencies are mounted in sealed brass holders contained in a specially designed box fitted with a heating element and thermostat. Four crystal holders for four working frequencies are provided, and a selector switch is incorporated in the box to enable any one of the four to be put into operation. The box contains also four spare crystal holders complete with spare crystals which can be quickly exchanged with the normal holders in case of failure of any of the normal crystals. The spare crystals and holders are maintained dry and at the right temperature by storing them in the temperature controlled compartment and are ready for instant use on their correct frequencies.

The master oscillator is followed by the coupling stage (comprising two 50 watt valves) which amplifies the master oscillator output and acts as a buffer to prevent reaction on the oscillator from the following stages. Such reaction would cause slight instability of the carrier frequency arising from impedance changes during modulation and keying. The coupling stage is a push pull circuit having two variable balancing condensers which, together with the grid to plate capacities of the valves, form a balanced capacity bridge having the grid input circuit across one pair of opposite corners, and the plate output circuit across the other pair of corners of the bridge. When the capacity balance is correct there can be no reaction between the input and output circuits. The amplifier is therefore stable against self oscillation, and in addition the master oscillator is completely separated so far as reaction is concerned from the succeeding stage.

The harmonic generators comprise two 250-watt tubes operating as amplifiers arranged for high distortion. For frequencies higher than 10 mega-cycles, both harmonic generators are used, but for frequencies below that value only one stage is required. The frequency is multiplied in each stage by 2 or 3, according to the frequency required.

The output of the frequency multipliers is a steady carrier at the frequency of transmission.

The next stage is the 500-watt amplifier which is the first of the three stages of high frequency amplification. It comprises two 250-watt valves in push pull. For telephony this stage is plate modulated, and for continuous wave telegraphy the keying operation is carried out in its grid circuit.

To secure a degree of linear modulation of 90% to 100% it is necessary that the low frequency modulating valves should be capable, without overloading, of impressing—across the plate circuit of the modulated high frequency amplifier—speech frequency voltages having peak values as high as the plate supply voltage of the modulated amplifier. This has been done, without resorting to step-up modulation transformers, by operating the modulating valves on a plate voltage about four times as great as the plate voltage on the modulated amplifier.

For continuous wave telegraphy, to ensure satisfactory operation for short waves, the 500-watt amplifier operates at 800 volts, which is well below the rated voltage of the valves.

For telephony, the plate voltage is reduced to about 400. By this means the carrier power is cut down to about a quarter of the peak or continuous wave telegraph power, when changing over from telegraphy to telephony.

The method of keying consists in throwing a high negative voltage on to the grids of the 500-watt amplifier from a small rectifier during "spacing."

The intermediate amplifier is of the push pull type, comprising two single ended, 2 kilowatt water-cooled valves. The valves work at a plate voltage of 4,000.

The power amplifier comprises two 10-kilowatt double ended valves working at 10,000 volts. The anode current grid volts characteristic of these tubes is shown in Figure 9.

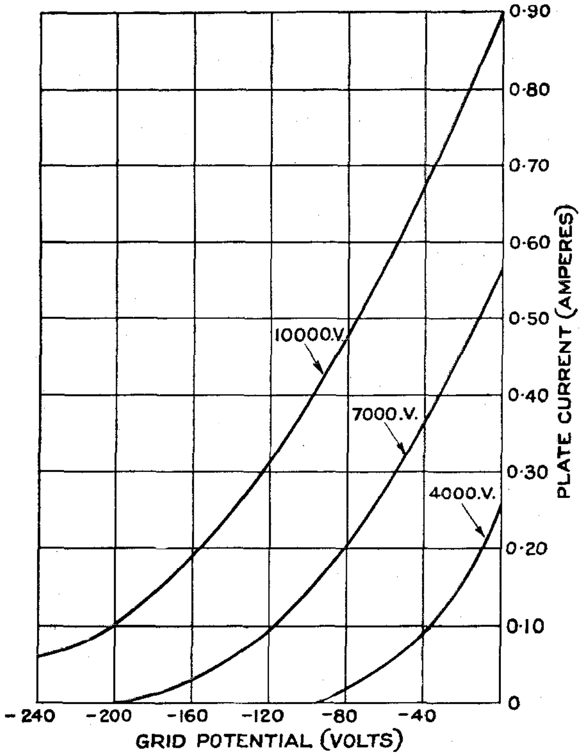


Fig. 9—Anode Current Grid Volts Characteristic–10 kw. tubes.

The circuits of the two amplifiers are almost exactly the same, being similar also to the circuits of the 500-watt amplifier and coupling stage. Each amplifier unit comprises essentially a tuned grid circuit terminating the coupling line from the preceding stage, a tuned plate circuit coupled to the outgoing transmission line, and a pair of valves and balancing condensers. The balancing condensers are variable and are accurately adjusted to prevent any reaction from the plate circuit back to the grid circuit.

The grid circuit is loaded with a resistance to swamp the variable grid impedance, and forms the major part of the load on the preceding stage. The resistance also serves as the means of adjusting the drive on the grids when the preceding stage is working into its correct impedance, and has its correct drive.

The grid and plate circuits are coupled to the incoming and outgoing transmission lines by condensers. The condensers are adjusted during the initial testing of the set to secure the correct impedance conditions, the grid condenser being adjusted to present an impedance of about 600 ohms at unity power factor to the incoming line. The plate condenser is adjusted to match the impedance of the output circuit to a 600 ohms antenna transmission line.

As has been pointed out at the beginning, the main object in designing the transmitter was to produce an equipment capable of efficient continuous service in the extension of a telephone or telegraph system. A number of these equipments has been manufactured; some have already entered into commercial service, including the Buenos Aires - Madrid and the British end of the London-New York radio link.

Short Wave Radio Telephone and Telegraph Receivers

By E. H. ULLRICH and R. E. GRAY

International Telephone and Telegraph Laboratories, Incorporated

OWING to the favourable propagation of radio waves between 30 and 6 megacycles (i.e., of wavelength between 10 and 50 metres) over long distances, there is an ever-increasing demand for commercial receivers covering this range. To turn to advantage the lowness of level of atmospheric interference at these frequencies, such apparatus must be of high sensitivity and reliability. Particular attention has to be given to other points also; tube noise must be kept low despite the high amplification involved, and effective steps have to be taken to render condensers and valves non-microphonic. As it is possible to receive telephony commercially with a radio field strength of the order of one microvolt per metre, and with an antenna consisting of a rod one-half a wavelength in height, an indication is obtained of the minimum telephonic input signal for which provision has to be made. The overall amplification must be sufficiently great to deliver to a commercial telephone line a level of +5 decibels, reference volume being taken as six milliwatts. A telegraphic service can be carried on very successfully with still weaker radio field-strengths. The sets here described are, in consequence, made to operate with signals of a fraction of a microvolt per metre.

The equipment is designed for the reception of short wave radio telegraphic or telephonic signals. The telegraphic signals are delivered in the form of tone telegraph impulses for aural reception at low speeds, and in the form of double current impulses for transmission over a telegraph line, in the case of high speed reception. The receiver is capable of operating at speeds up to 300 words per minute with the Morse code.

Wavelength Range and Band-width

The operating wavelength of the radio receiver is continuously variable over the range 10 to 100 metres (30,000 − 3,000 kilocycles). Tuning is effected by means of variable condensers in conjunction with interchangeable coil units. Each coil covers a considerable wavelength band, so that in many cases the desired change of wavelength can be effected by means of the tuning condensers alone. The band-width is from 200 to 5,000 cycles.

Description of Equipment

A block diagram of the whole receiver is given in Figure 1. The equipment comprises in brief a receiver proper working on the super-heterodyne principle, an automatic gain control for telephony, some auxiliary oscillators, a gain control entitled a "signal limiter" for telegraphy, and certain low frequency measurement and control apparatus. Two aerial connections are shown to the receiver to indicate diagrammatically that a directive antenna system is ordinarily employed. The combination of the signals picked up on a "collector" and on a "reflector" array is effected in the receiver itself, the energies from the two separate parts of the antenna system being brought to the receiver by two single-wire transmission lines so arranged that any high frequency voltages picked up in them both will oppose each other in the grid coil of the first detector, and will balance out.

To render unmodulated C. W. signals audible, a constant frequency 1,000 cycles oscillator is provided, and modulation of the C. W. signals themselves by the 1,000 cycle note is carried out

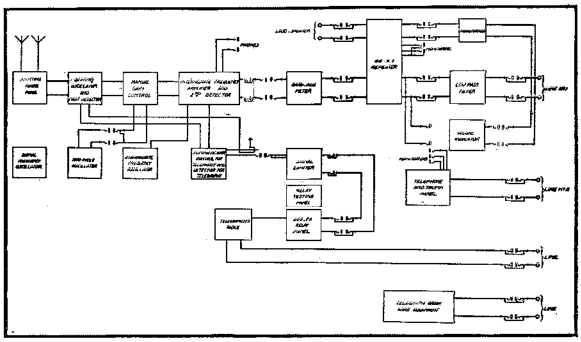


Figure 1—Block Diagram of Short Wave Radio Telephone and Telegraph Receiver.

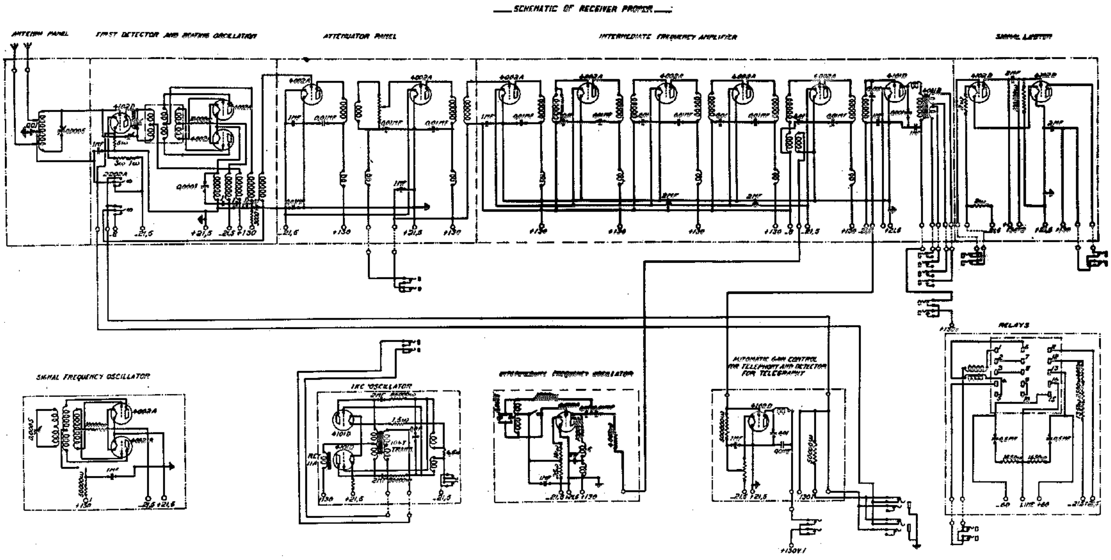

SCHEMATIC OF RECEIVER PROPER
ANTENNA PANEL
FIRST DETECTOR AND BEATING OSCILLATOR
ATTENUATOR PANEL
INTERMEDIATE FREQUENCY AMPLIFIER
SIGNAL LIMITER
SIGNAL FREQUENCY OSCILLATOR
INTERMEDIATE FREQUENCY OSCILLATOR
RELAYS

Figure 2—Circuit Diagram of Short Wave Radio Telephone and Telegraph Receiver.

at intermediate frequency. C. W. telegraph signals are, therefore, received in the output 'phones of the set as a keyed note of perfectly steady pitch. The circuit diagram of this oscillator is given in Figure 2. A variable frequency oscillator, that covers the band of the intermediate frequency amplifier, is provided. By this means it is possible to employ heterodyne reception of C. W. signals. Although reception by means of the 1,000 cycle modulation has the advantage that a very steady output frequency is obtained, even though the set be subject to violent mechanical vibration, or to very large variations of H. T. and L. T. supplies, it fails when any loud extraneous noise is produced in the receiver, since the noise itself is modulated by the 1,000-cycle note and acts as a substitute for the C. W. signal.

In ordinary commercial operation, the receiving set must be installed where electromagnetic interference is absent. When, however, the C. W. signal is so weak that it begins to sink into the atmospheric or tube noise, it is more easily readable by heterodyne reception. The Intermediate Frequency Oscillator, moreover, serves another purpose; it is possible to check the band passed by the Intermediate Frequency Amplifier at any time and to adjust the Beating Oscillator so that, especially in the case of telephony, the intermediate frequency corresponding to the carrier of the distant station lies in the middle of the frequency band of the I. F. amplifier. The circuit diagram of this oscillator is given in Figure 2.

In order to facilitate exact tuning of the receiver, an oscillator at signal frequency is provided. If this oscillator is not employed, it is difficult to tune the set when fading is taking place. As the incoming carrier produces, when heterodyned in the Intermediate Frequency Amplifier by the Intermediate Frequency Oscillator, an audible output note, it is easy to adjust the Signal Frequency Oscillator to within a few cycles of the incoming carrier by simply tuning it to give the same audio note. The Signal Frequency Oscillator is strong enough to swamp the incoming waves and, by reason of the presence of a steady local signal, correct tuning of the receiver is facilitated. The circuit diagram of this oscillator is given in Figure 2.

After traversing the Intermediate Frequency

Amplifier, the signal follows one of two different paths according as it represents telegraphy or telephony. In the former case it passes through the "signal limiter," which is described more fully below, to the telegraphist's table, and thence to the line. In the case of telephony, it enters a band-pass filter, which serves to ensure the suppression of frequencies outside the band 200—5,000 cycles. Thence the signal passes into a standard 44-A-1 Repeater, which introduces a gain that may be varied up to 40 decibels. A volume indicator is provided to permit of the adjustment of the gain of the repeater to the proper value.

A layout drawing of the front view of the set is given in Figure 3.

Bay No. 1 is the battery supply bay and contains the meters, fuses, relays, etc., associated with the application of the various battery supplies to the radio receiver. The second bay contains the speech control apparatus, telegraph relay and order wire circuits. The third bay contains the signal frequency and intermediate frequency testing oscillators and the signal limiter. The last bay mounts all the panels comprising the radio receiver proper, namely, the antenna panel, first detector and beating oscillator, the intermediate frequency amplifier, the automatic gain control and the testing jacks. The key to the numbers shown in Figure 3 is as follows:

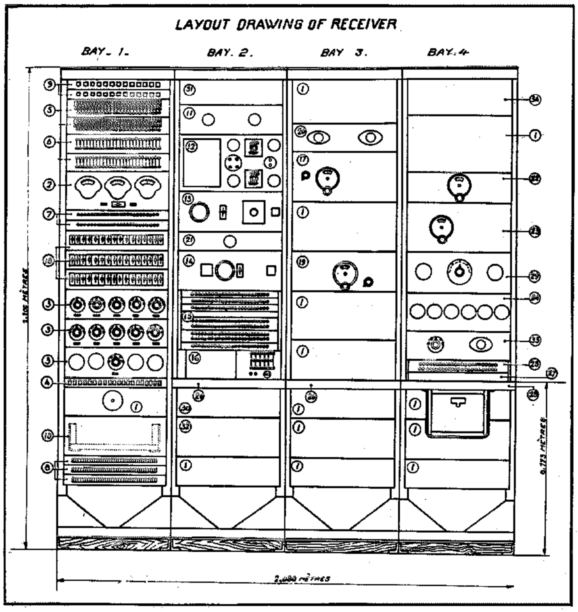


Figure 3—Layout Drawing of Short Wave Radio Telephone and Telegraph Receiver.

1. Blank panels.
2. Meter panel.
3. Rheostat panels.
4. Condenser panel.
5. Alarm fuse panels.
6. Fuse panels.
7. Alarm lamps.
8. Resistance panels.
9. Relays.
10. Dry batteries panel.
11. 1,000 cycle oscillator.
12. 44-A-1 Repeater.
13. Volume Indicator.
14. Testing panel.
15. Jack Strips.
16. Telephone and Trunk panel.
17. Signal Frequency Oscillator.
18. Keys.
19. Intermediate Frequency Oscillator.
20. Signal Limiter.
21. Relay panel.
22. Antenna tuning panel.
23. Beating oscillator and 1st detector.
24. Intermediate Frequency Amplifier.
25. Jack Strip.
26. Operator's shelf.
27. Blank panel.
28. Shelf with drawer.
29. Manual Gain Control.
30. Filter.
31. Filter.
32. Transformers.
33. Automatic Gain Control and Detector for Telegraphy.
34. Antenna Lead-In panel.

Antenna Panel

This contains the antenna tuning circuit which is designed for connection through a pair of transmission lines to a directive antenna array. The circuit consists of a single coil tuned by a variable condenser, the centre point of the inductance coil being grounded through a fixed condenser of 0.01 microfarads. The two transmission lines are connected to variable tapping points on the inductance, whereby the impedance

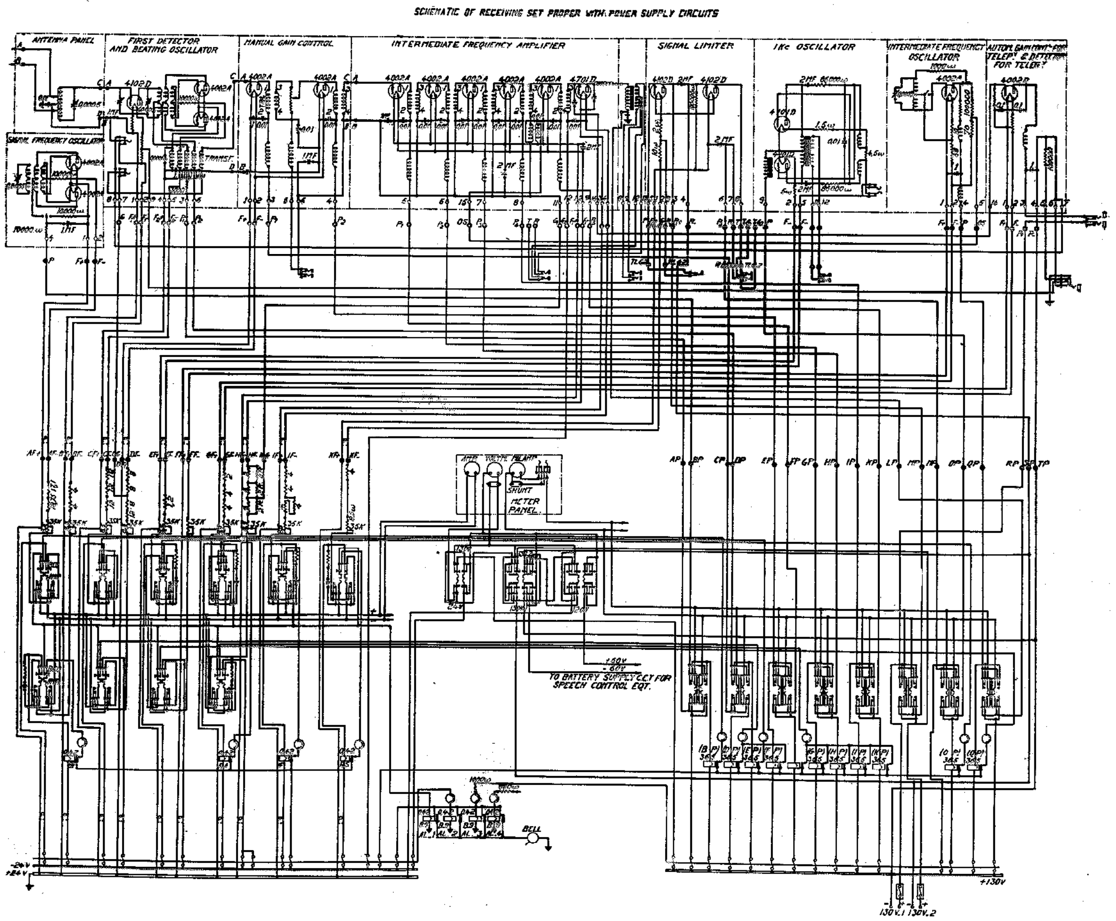

SCHEMATIC OF RECEIVING SET PROPER WITH POWER SUPPLY CIRCUITS
ANTENNA PANEL
FIRST DETECTOR AND BEATING OSCILLATOR
SIGNAL FREQUENCY OSCILLATOR
MANUAL GAIN CONTROL
INTERMEDIATE FREQUENCY AMPLIFIER
SIGNAL LIMITER
1Kc OSCILLATOR
INTERMEDIATE FREQUENCY OSCILLATOR
AUTOM. GAIN CONT. FOR TELEP. & DETECTOR FOR TELEG.
4102D
4002A
4701D
4101D
4002B
TRANSF.
SHUNT METER PANEL
TO BATTERY SUPPLY CCT FOR SPEECH CONTROL EQT.
BELL
-24V
+24V
+130V
130V.1
130V.2

Figure 4—Diagram of Receiver Circuit Showing Power Supply Circuit.

of the line may be matched, and the two lines balanced to earth. The inductance coil is replaceable, enabling the large frequency band to be covered.

The antenna panel is followed by a two-stage transformer coupled amplifier operating at the signal frequency. The coupling transformers are interchangeable and are tuned by variable condensers. This amplifier is not shown in the drawings or photographs of the receiver.

The Beating Oscillator and First Detector

In order that the receiver may be easy to operate, it is necessary that the tunings of the first detector grid circuit, and of the Beating Oscillator should be quite independent—that there should, in other words, be no coupling between these circuits. For this reason, the Beating Oscillator voltage is introduced in the plate circuit and the signal voltage in the grid circuit of the first detector, which operates on the lower bend of the plate current grid voltage characteristic. It is, however, necessary to neutralise the grid-to-plate capacity of the detector tube by means of a small condenser, which is adjusted in the laboratory, but which is made variable so that it can always be readjusted in service. The adjustment can be checked by short-circuiting the input from the antenna, when there will be an appreciable change in the plate current of the first detector, if the balancing condenser is out of adjustment.

The principle of symmetry, so important in short wave work, is preserved in the Beating Oscillator, which is "push-pull." This construction facilitates a perfect balance with the neutralising condenser, that is to say, a balance which is independent of the tuning of the set. As is well known, an arrangement, that is physically unsymmetrical, is usually at short waves electrically unsymmetrical, on account of the low impedance of any small capacity unbalances, and of the relatively high impedances caused by the inductance of the leads. The push-pull oscillator has, in addition, the advantage of added frequency stability—an important point when it is remembered that a variation of 10,000 cycles in 20 million is all that is required to tune to the neighbouring channel. The oscillator coil contains three windings, one of which is of copper tube, the other two—those connecting to the grids and plates of the tubes—being contained inside the first. By this means, the coupling between the coils is kept close to 100%, so that no coupled circuit effect is noticeable when the oscillator is being tuned. On the other hand, the "skin effect" causes all the high frequency currents to pass onto the outer copper tube, which is made of 5 mm. outer diameter copper, and, therefore, has reduced losses. By this means the decrement of the oscillator circuit is kept low and the frequency stability improved. The 3-winding oscillator coil is assembled as an interchangeable unit, several such coils being used to cover the wavelength range.

Intermediate Frequency Amplifier

The intermediate frequency amplifier operates at a frequency of 500 kilocycles, and has an amplification of about 100 decibels. Seven stages of transformer coupled amplification are provided.

The second detector operates on lower band of the anode current grid voltage characteristic.

The Gain Controls

A manual gain control is provided to permit of a variation of output level of 40 decibels in one decibel steps. In order to overcome the effects of fading, an automatic gain control is provided. It can be thrown in or out of circuit by means of a switch. It contains a single 4102-D (high impedance) tube operating as a third detector with its grid connected to the grid of the second detector located on the intermediate frequency amplifier panel. A resistance of 100,000 ohms is connected in the plate circuit of the gain control tube, and a grid potentiometer is provided whereby the plate current of the tube may be adjusted. This tube fulfils two functions: first it operates as a gain control tube when working on telephony, and secondly as a detector tube when receiving high speed telegraphy. When operating as an automatic gain control tube, the drop in voltage across the 100,000 ohm anode resistance is applied to the grid of the first detector and first amplifying tube. An increase in the strength of the received signal causes an increase in the anode current of the gain control tube, and thus an increase in the negative grid bias applied to the first detector and first amplifying tube. This increase in the negative grid bias reduces the gain of the receiver and thus maintains a constant output level. When operating as a detector for high speed telegraphy, the voltage across the 100,000 ohm anode resistance is applied between grid and filament of the first tube of the signal limiter; the limiter in turn

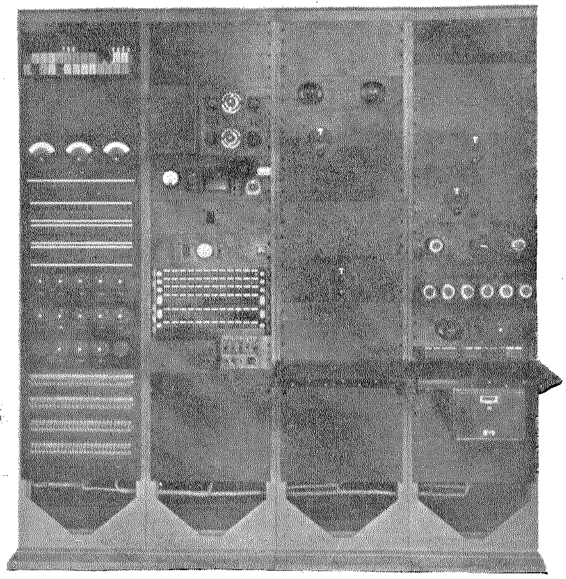


Figure 5—Front View of Receiver.

operates a 209 FA relay and the high speed telegraph apparatus.

Signal Limiter

The signal limiter is in effect a two-stage resistance coupled amplifier which may be patched into the output of the telegraph detector when required, the limiter being provided with input and output jacks for this purpose. The circuit is that of a direct current amplifier thus enabling it to operate on the direct current impulses corresponding to the reception of continuous wave telegraph signals. The limiter employs two 4102-D (high impedance) tubes. The anode current of the second tube is limited to zero during spacing signals, and to 2.7 milliamperes maximum during marking signals.

The limiter is normally patched between the output of the third detector and the receiving relay, and the gain of the receiver is adjusted so that with the lowest received field strength, the marking current in the anode circuit of the second valve is not less than the minimum required to operate the receiving relay (2.3 milliamperes). Any increase in the field strength will then not cause the marking current through the relay to exceed 2.7 milliamperes, and consequently bad operation and chattering of the relay due to an excessive marking current is avoided.

Relay Panel

The relay panel mounts the receiving relay together with the associated circuit elements, designed to deliver double current impulses at ± 60 volts to the line. The relay is a standard 209 FA permalloy relay and is capable of operating at speeds up to 120 cycles per second corresponding to 320 words per minute in the Morse Code. The contacts of the relay are suitable for dealing with a current of about 20 milliamperes. The circuit elements associated with the relay include a "kick transformer" for sharpening up the action of the relay.

Battery Supply Circuits

The radio receiver and speech control apparatus require a filament supply at 24 volts with the positive earthed. The total current drawn by the receiver with all tubes switched on is approximately 10 amperes. In the filament supply circuit to each panel there is an alarm fuse, a rheostat and a three-way key. When the key is in the non-locking position, an ammeter is connected in series with the filament supply to that panel, and when in the locking position the filament supply is cut off.

Alarm relays are connected in series with the filaments of the signal limiter and the three detector tubes, so that failure of the filament supply to any of these tubes causes an alarm lamp to light, and the alarm bell to ring. The voltage of the filament battery may be measured by depressing the 24-volt key and reading the voltage on the meter panel.

The main plate battery supply is at 130 volts with the negative earthed. The total current drain is approximately 0.15 amperes. In addition to the main plate battery, the automatic gain control tube and the first tube of the signal limiter each require a separate dry cell battery of 130 volts. These batteries are mounted on special shelves at the rear of the radio receiver. The current drain from each battery is about 0.5 milliamperes. These two special batteries are insulated from earth.

Alarm fuses are connected in the plate circuit of each tube, and alarm relays are provided in the plate circuits of all tubes except the detectors and the two signal limiter tubes. Failure of the plate current of any of these tubes operates an alarm lamp and the alarm bell. By means of a series of keys, the plate current of any tube may be read on a double range milliammeter provided on the meter panel. By operating the appropriate key, the voltage of each of the three plate batteries may be measured.

For telegraph purposes, a 120-volt battery with the centre point earthed, delivering the required value of line current, is supplied. Fuses for this battery are provided on the power supply bay.

A diagram of the whole receiver including power supply circuits and a front view of the receiver are given in Figures 4 and 5.

Thermionic Vacuum Tubes for Short Waves

By W. T. GIBSON

International Telephone and Telegraph Laboratories, Incorporated

THE advent of the use of short waves brought in its train many new difficulties for the vacuum tube designer, especially when the demand arose for more and more power. For small powers up to and including the 250 watt tube, the air cooled form of tube already used for long waves proved suitable also for short waves. However, the high power long wave water cooled tube which had reached a high state of perfection for wave lengths over 60 metres required various modifications for short wave working.

Vacuum tubes intended for very short waves retain the feature of an external anode cooled by a circulated liquid but must be specially designed in order that the following difficulties may be avoided:

1. Heating effects caused by high frequency losses in dielectrics.
2. Heating effects caused by the very large high frequency currents which are encountered, and the very high value of the high frequency resistance, due to skin effect.
3. External insulation difficulties due to the ease with which the air breaks down at very high frequencies.

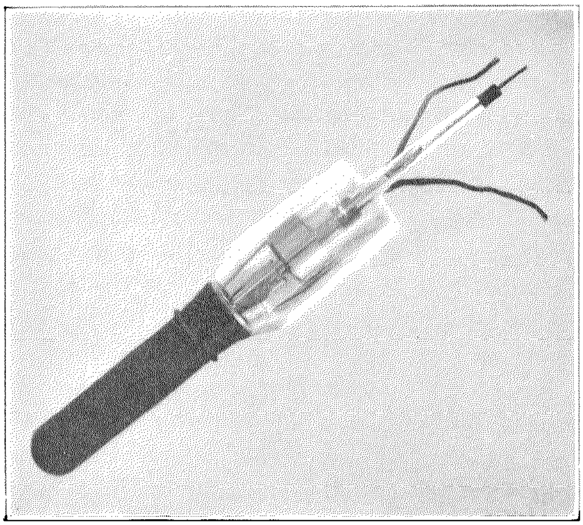


Figure 1—SS. 1966 Short Wave Vacuum Tube.

4. The demand for low electrode capacity.

The first trouble is one which probably causes the greatest difficulty in the design of these tubes.

The effect usually shows up at places where high electrostatic fields exist. If these fields pass through the glass envelope for example, the dielectric loss which occurs is often sufficient to raise the temperature of the glass to the softening point very quickly, and a very characteristic failure is caused in which a small hole is made in the envelope, with the edges rounded and pointing inwards in accordance with the way the glass is pushed in by the air pressure, forming a kind of dimple. Very often, the shape of these holes is such as to indicate quite clearly the direction of the field at the point of failure.

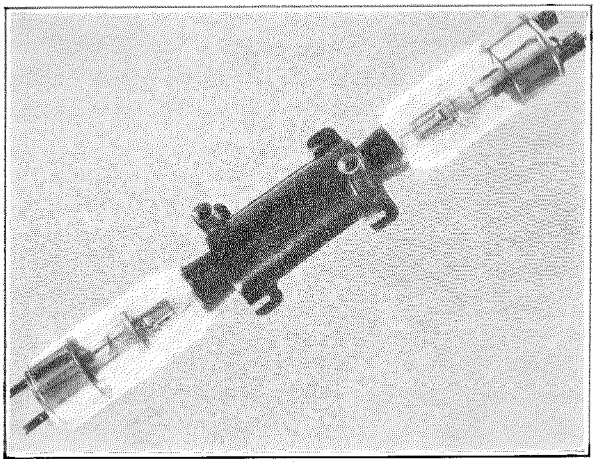


Figure 2—SS. 1968 High Power Short Wave Vacuum Tube.

Sometimes, the heating is not sufficient to cause an actual fusion of the glass but, on the other hand, long continued operation causes a small evolution of gas which ruins the tube. When the heating occurs quite close to one of the electrodes, there may be a considerable electrolysis of the glass which leads to an early failure, either by cracking or by "softening" of the tube.

In the same way, the use of dielectrics in the active part of the tube for supporting or separat-

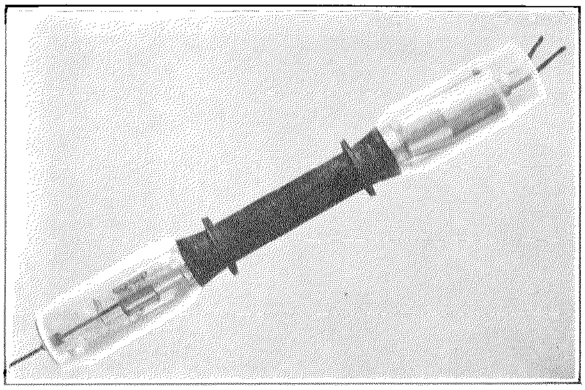


Figure 3—Experimental High Power Short Wave Vacuum Tube Ready for Pumping.

ing portions of the structure is very considerably limited. "Steatite" and other similar materials which are commonly used for such purposes may easily be melted into a vitrified mass if placed in such a position as to be subjected to an intense high frequency field.

On account of the difficulties enumerated a series of tubes for short waves have been developed, in which a special system of shielding has been incorporated. The use of the screen for the anode has been considerably extended. This screen is electrically connected to the anode within the tube and extends beyond the end of the copper glass seal. In long wave tubes for very high voltages this serves as a protection for the glass at the edge of the seal where piercing by electronic bombardment occasionally occurs. In the case of the short wave tube, however, the danger of piercing is not very great, but by means of this shield the intense field at the edge of the anode is removed from the glass and distributed uniformly round the vacuous space. At the same time, when necessary, the tubes are provided with shields on the grid and filament to distribute the field in the vacuum in the best manner possible, and to diminish the field which intersects the glass.

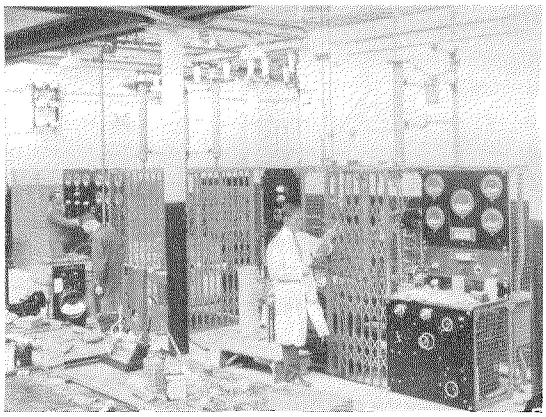
In the higher power vacuum tubes the anode is made with a glass bulb at each end, the grid being sealed into one end and the filament into the other. This arrangement improves the tube very much but considerably increases the difficulty of manufacture, especially the operations of sealing the filament and grid into the anode. The difficulty will be realised when it is considered that the glass blower has to manipulate the anode assembly with its two bulbs while sealing in each electrode, and that owing to the use of the screens in the anode it is impossible to see the far end of the electrodes in order to make sure that it is centrally situated. To overcome this difficulty, an ingenious method is employed; a small spark coil is connected between the anode and the electrode being sealed in, and a parallel spark gap is used of such a length that when the glass blower has sealed the electrode exactly in the correct position the spark passes over the auxiliary spark gap instead of within the tube. However, an entirely new design of tube is now being developed and will probably be soon available, in which the sealing-in is done in such a way that the electrodes are automatically centered during the operation.

The high values of high frequency currents and the magnitude of the factor of skin effect may cause so much heating of apparently quite large conductors within the vacuum tubes, that very special consideration has had to be given to the dimensions of the leads, and they have been designed so that the metal in physical contact with the glass does not carry current.

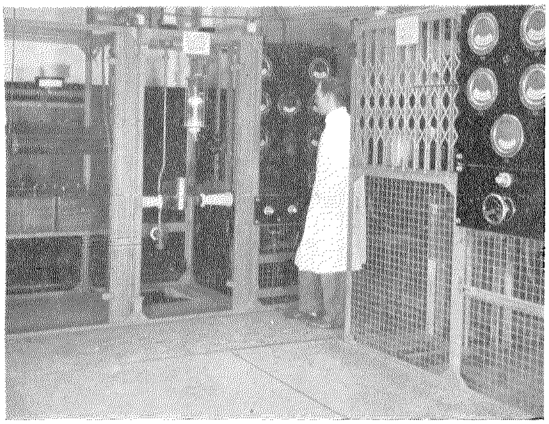
For the design of circuits and for easier operation it is very important that the capacity between the electrodes of short wave tubes should be kept down to as low a value as possible; the double-ended arrangement in which the grid and filament are brought out at opposite ends is one very effective means by which this capacity can be appreciably reduced. At the same time, since it gives an improved tube from the operating stand point, the tube with lower capacity is preferable because the high frequency currents through the leads are reduced.

With the double-ended type of construction it is possible to use a self contained water jacket or a separate water jacket through which the tube is inserted. The former method has been adopted for the following reasons:

1. A much more satisfactory water flow around the anode can be obtained.
2. There is less danger of breaking the tube when changing tubes.
3. There is less danger of flooding the transmitter when changing tubes.



High Power Vacuum Laboratory—High Voltage Testing Equipment.



High Voltage Rectifier and Pumping Stations—Vacuum Tube Laboratory Pumping Room.

4. A separate water jacket is of necessity extremely large and clumsy.

5. It is difficult to make water-tight joints at both ends of a separate jacket.

The combined water jacket has the disadvantage that it is more difficult to clean the anode if it becomes very dirty; this, however, is not a very serious objection because these tubes are operated in equipments where a closed circulating system is employed, and in order to avoid electrical leaks through the water supply, soft water, which leaves practically no deposit, is used. The connections to the water jacket are threaded for a standard pipe fitting, and it is a very simple matter to make the connections by means of a standard union.

The water jacket carries four lugs by which it can instantly be put into position or removed from the set. Of course, in the case of the low power tube, which is single-ended, a standard water jacket is used and the anode is inserted in the same way as the anode of a long wave tube, using a screw down ring to compress a packing ring which makes a water-tight joint with a bead on the top of the anode.

As these tubes are practically always used in push-pull arrangements, very great care is taken to insure that they have characteristics sufficiently uniform to operate under the above mentioned exacting conditions without any difficulty.

The pumping arrangements for double-ended tubes are of necessity somewhat different from those for single-ended tubes, but by the methods adopted it is possible to secure for all these tubes a vacuum of the very highest order, such as is obtained in the long wave vacuum tubes.

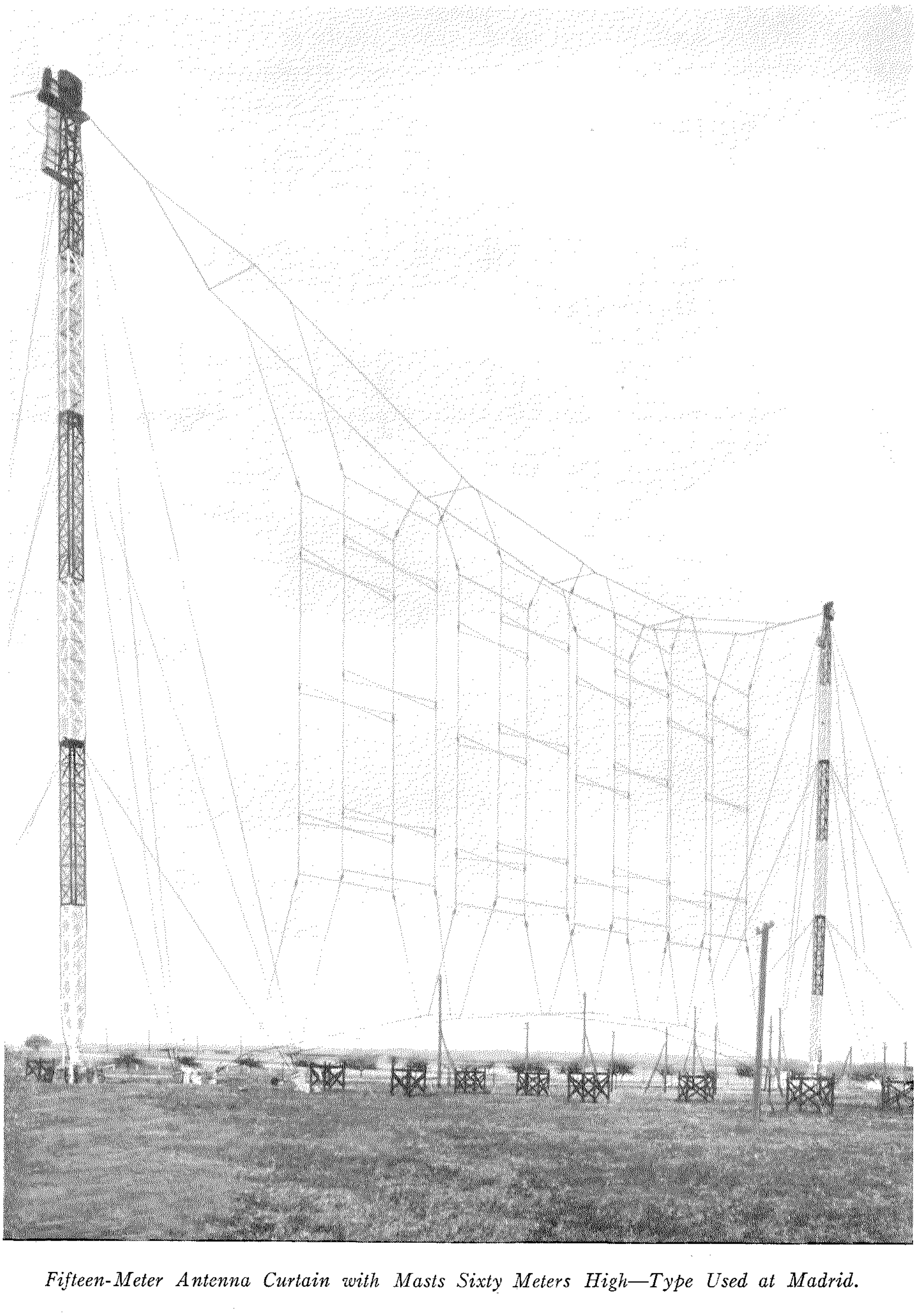
These tubes have been tried out in commercial short wave transmitters, with highly satisfactory results, giving in all cases the required output with continuous operation.

Figure 1 is a photograph of the SS. 1966 short wave tube, Figure 2 the completed 1968 high power short wave tube, and Figure 3 shows an experimental short wave tube of higher power, ready to be pumped.

The following table gives some information on the characteristics of the various water cooled tubes which have been standardised. The values of the constants vary somewhat from tube to tube and the figures are given only as an indication. The maximum anode dissipation is that which the anode can support continuously with a rapid water circulation, and practically speaking is a function entirely of the anode dimensions and has nothing to do with the electrical characteristics of the tube. The maximum output given is only given as an indication of the power that can be obtained when operating as an efficient oscillator. The actual power obtainable in any circuit depends on a number of factors and thus is limited by the method of operation.

STANDARDISED SHORT WAVE VACUUM TUBES

Tube	Type	Filt. volts	Filt. amps.	Emission	Anode volts	μ	R_p	Capacity in $\mu\mu f$			Max. anode dissipation continuous	Max. Output
								g f	f p	p g		
SS. 1966-2	Single-ended	14	24	2.6 amps.	4000–5000	23	8500	16	6	20	10 KW.	1 KW.
SS. 1966-3	Single-ended	14	36	4 amps.	4000–5000	23	7000	18	6	20	10 KW.	1.5 KW.
SS. 1968	Double-ended	22.5	41	5.5 amps.	8000–10000	40	6000	14	11	30	15 KW.	10 KW.
SS. 1971	Double-ended	20	64	9.5 amps.	8000–10000	18	3000	10	11	26	15 KW.	15 KW.



Fifteen-Meter Antenna Curtain with Masts Sixty Meters High—Type Used at Madrid.

Short Wave Directive Transmitting and Receiving Antennas

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International Telephone and Telegraph Laboratories, Inc.

and N. K. FAIRBANK
Engineering Department, International Telephone and Telegraph Corporation

AS is well known, radio waves are similar in physical nature to light waves, both being electromagnetic phenomena propagated through space by vibrations or disturbances in the ether. The two differ from each other only in the frequency with which the vibration occurs. Radio waves range in frequency from about 10 kilocycles to 10^5 megacycles. At the latter point radio waves merge into the infra red portion of the light spectrum.

Since radio waves are similar to light it is to be expected that they could be reflected and focused into a beam as are light rays. In fact, in Hertz's original experiments he used a parabolic reflector very similar to a light reflector. The wavelengths used in long wave radio communication, however, are so great that any type of reflecting or directive structure would be prohibitively large and expensive. It was not until short waves began to be used for radio communication that it became possible to build efficient and economical directive antennas.

The short wave antennas on the Buenos Aires-Madrid radio channel do not employ the parabolic reflector of Hertz. Another property of electromagnetic waves, that exhibited in the refraction of light, is made use of. If a simple vertical Hertz half wave antenna is excited by signals of its characteristic frequency, it will radiate disturbances into the ether. Viewed in a horizontal plane these disturbances will be equal in all directions about the wire. This is the condition shown in Figure 1-a. If now a second antenna is placed one-half wavelength from the first and excited in the same phase, it will be seen that in a direction normal to the plane of the two wires and at a point remote from the antenna the radiations will both add together. In the plane of the wires, the radiations from one antenna will be one-half wave behind those from the other and hence will completely cancel. The distribution of field about such an antenna system is shown in Figure 1-b. It will be seen that with this arrangement radiations occur in either direction normal to the plane of the two wires.

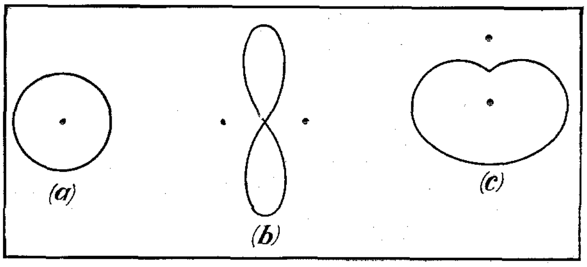

Figure 1—Antenna Radiation Patterns.

If now two vertical antennas are placed one-fourth wavelength from one another and excited so that the voltage in one leads that in the other by 90°, the distribution of field shown in Figure 1-c occurs. In other words, the field cancels on one side of the antenna while it adds on the other, a reflector effect being obtained. By combining the effects shown in Figure 1-b and 1-c the elements of directive antenna employed in the Buenos Aires-Madrid channel is obtained.

All the transmitting antennas described below depend for their action on these principles. Instead, however, of employing only two phased radiators one-half wavelength apart, as shown in Figure 1-b, as many as sixteen are placed one-half wavelength apart in one plane, each being backed by its reflector, as shown in Figure 1-c. The reflectors are ordinarily parasitically driven by the radiator. In like manner, placing of properly phased conductors vertically above one another produces a similar directive effect in the vertical plane. The greater the number of superimposed radiators the sharper will be the vertical directivity.

The function of a transmitting antenna is to radiate the output of the transmitter in the desired direction as efficiently as possible. The transmitting antenna of a point to point system should therefore be as directive as possible, both horizontally and vertically. The horizontal directivity is limited by the economical length of the antenna and the physical accuracy with which it can be directed toward the desired objective. The vertical directivity should be about 10° to 15° for frequencies of 20,000 Kc. and about 20° for the frequencies of 10,000 Kc. Vertical directivity greater than this can be secured but results in a ray so sharply directed that its operation is erratic, due to sudden changes in the height of the Heaviside Layer.

If we consider the vertical wire A. B. C. D. . . OP (Figure 2) on which are present stationary waves and bend it according to the pattern of Figure 3, the currents will then be distributed as shown in Figure 3. It will be seen that in the vertical portions the currents are in phase, while in the horizontal portions the currents cancel out due to opposite phase. In the end sections O N and G F, the currents are equal and in reverse phase in each of these half sections. The radiation of the horizontal portions is therefore practically nil.

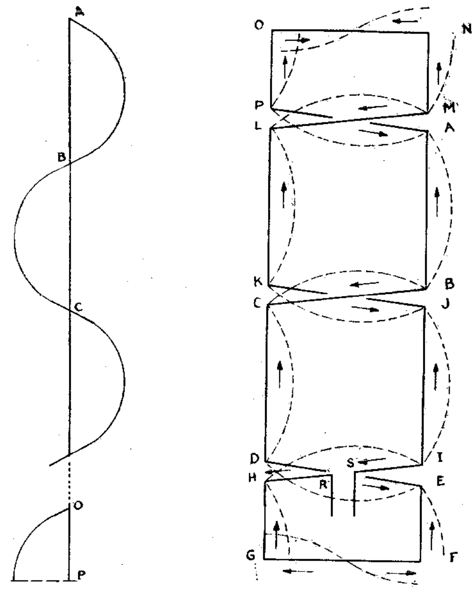

Figure 2—Figure 3—Vertical Wire (Figure 2) Bent According to Pattern of Figure 3, Illustrating Current Distribution.

The arrangement shown in Figure 3 constitutes a group of vertical antennas in phase. The antennas of the Buenos Aires-Madrid channel consist in general of 6 to 8 groups of this type placed one-half wavelength from one another in the same plane. Each of these groups is energised by high frequency transmission lines, consisting of two wires, at a point of current maximum such as R and S, and in such fashion that the current in the vertical sections is in phase for all groups. Behind this curtain is another similar antenna curtain which serves as a reflector. The horizontal directivity for such an array is shown in Figure 4.

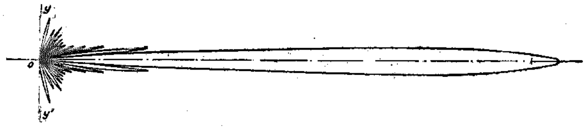

Figure 4—Distribution of Field in a Horizontal Plane of an Antenna Array Having Both Radiators and Reflectors.

Transmitting Antennas†

The antenna curtains and reflectors at Madrid are suspended on two cables between guyed masts 60 m. high (See Figure 5). A spreader consisting of a steel tube $\frac{\lambda}{4}$ wavelength long separates the cables supporting each curtain. The strain at the top of the towers is 5 tons and is automatically regulated by a counterweight. The two supporting cables are attached to winches in order that the curtains may be raised and lowered. A messenger cable to which a counterweight is attached maintains the tension at 5 tons when the antenna is being raised and lowered. The vertical wires of each curtain are kept in tension by counterweights acting through a system of pulleys. Very large factors of safety have been adopted and in no case does the tension in an element of the curtain exceed 150 kgms.

At Buenos Aires precisely the same antenna is employed as far as theoretical considerations are concerned. Practically, however, the antenna curtains are suspended from 175′ steel masts. Seven of these masts are employed for an antenna system consisting of three frequencies. The masts are anchored by means of head guys and the curtains can be raised and lowered completely independently of the head guys by means of winches. The method of feeding the antenna curtain, illustrated in Figure 6, differs slightly from that in use at Madrid. A view of the completed Buenos Aires antenna is shown in Figure 7. On any given frequency the gain of such a system over a single vertical half wave antenna is approximately 15 to 20 db.

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† Due to the speed with which this project was consummated, the transmitting and receiving antennas originally installed differ somewhat from the description given in this article. However, the final arrangements will be in effect in Madrid at about the time this issue of *Electrical Communication* reaches the reader, and not long thereafter, also, in Buenos Aires.

Transmission Lines

The transmission lines which simultaneously feed all the antenna groups should satisfy the two following conditions:

(1) All the antennas should be excited by currents in the same phase and equal in magnitude.

(2) At no point in the line should there be reflection of energy back toward the transmitter.

If the antenna groups of the same curtain are excited by branch lines from the transmission line, it is necessary in order to satisfy the first condition that the length of transmission line be the same to each antenna element from the transmitter and that the branch lines be symmetrical. Since the speed of propagation is the same in the identical branch lines and the length of the latter are equal, the dephasing due to these equal distances will be the same for all groups of antennas.

To satisfy the second condition and avoid the presence of stationary waves on the transmission lines between the transmitter and the antennas, it is necessary to match the impedances of the transmission line in such a fashion that the line will be terminated by an impedance equal to its characteristic impedance.

Receiving Antennas

The directive properties of the antennas described in the first part of this paper were explained on the basis of a transmitting antenna. It will be seen that the theory is equally applicable to a receiving antenna. Assuming in Figure 1-b that the two antennas are so interconnected they are in phase for transmission, an incoming signal will produce a disturbance in each antenna. If the signal arrives from a direction normal to the plane of the two antennas the voltage induced in each wire will be in phase and the two resultant currents will add. If, however, the signal comes from any other direction, impulse will arrive at one antenna before it reaches the other with a result that the currents will not be in phase.

For various reasons, however, a transmitting

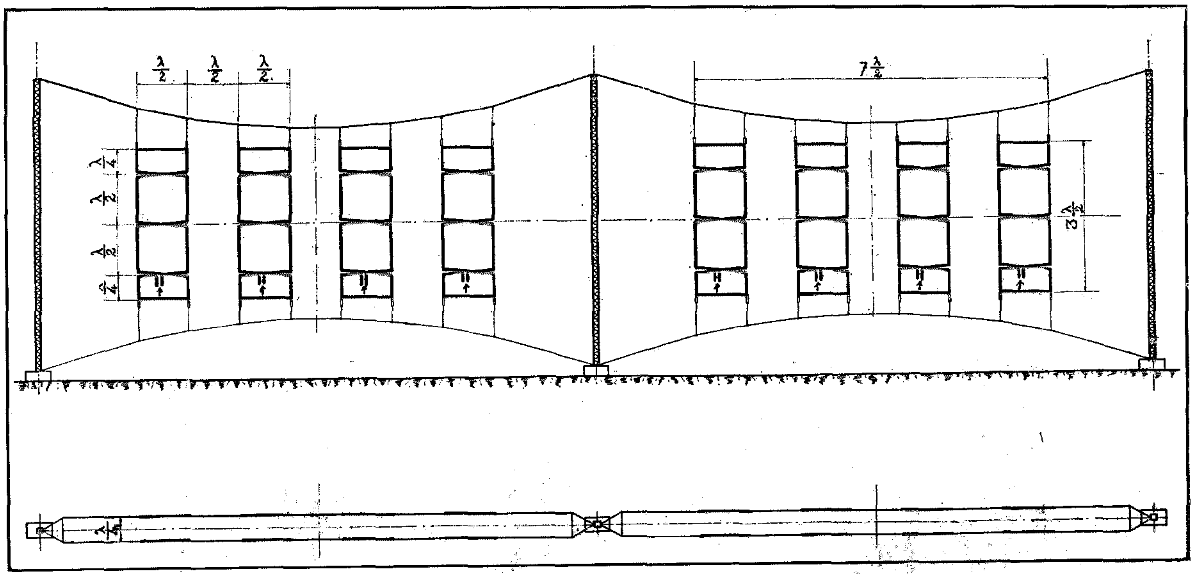

Figure 5—Plan of Madrid Transmitting Antenna.

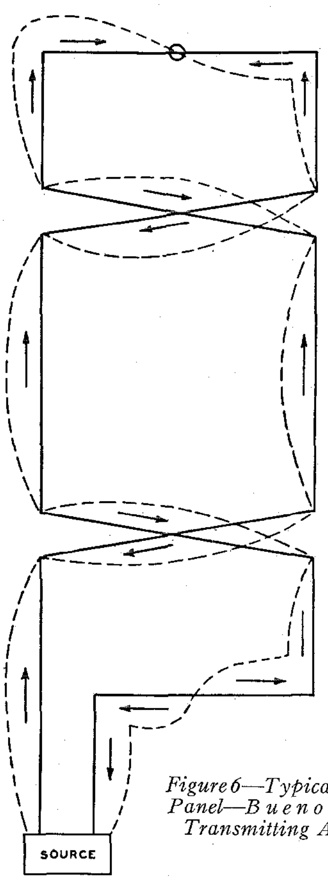

Figure 6—Typical Antenna Panel—Buenos Aires Transmitting Antenna.

antenna does not make a particularly satisfactory receiving antenna. It is desirable that the transmitting antenna deliver a ray very narrow in the vertical plane. It has been found that an incoming signal arrives at the receiver at all angles from horizontal to vertical, depending on the manner in which it has been reflected during its passage. The most common angle is between zero and sixty degrees from the ground and an efficient receiving antenna should be equally responsive over this range. The antenna is preferably constructed on a wood frame avoiding as much as possible the use of steel towers or other extraneous reflecting objects which will reduce the directional properties of the antenna by introducing unwanted reflections onto the antenna elements.

A type of antenna which answers these requirements is that shown in Figures 8 and 9. This type of receiving antenna is used both at Madrid and Buenos Aires. It consists essentially of a long wire so folded in space that the vertical elements act as signal collectors while the horizontal members act as interconnecting lines. Both vertical and horizontal members are each one-quarter wavelength long. The voltages induced in the vertical elements by the signal are equal, but the phase relations depend on the direction of approach of the wave. A signal from

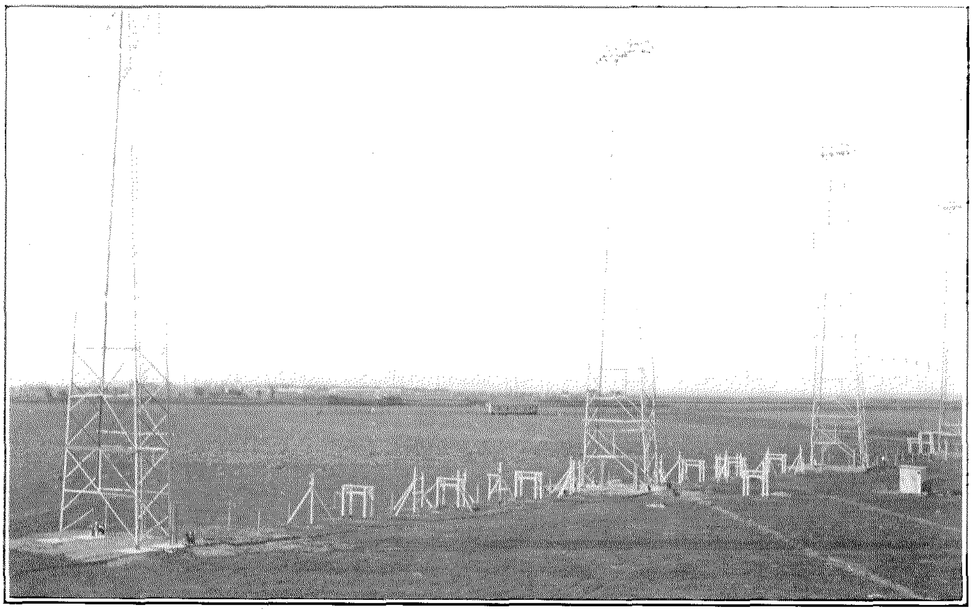

Figure 7—Buenos Aires Transmitting Antenna.

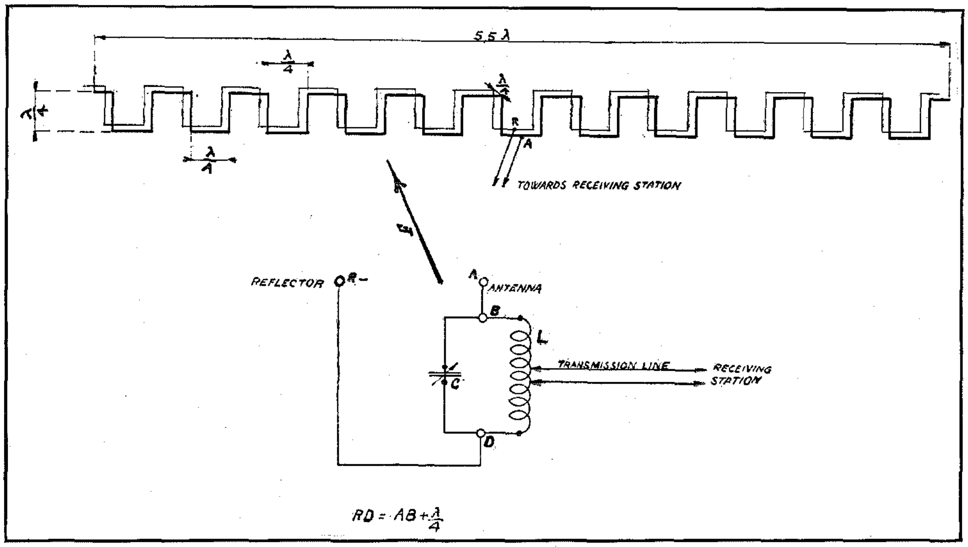

Figure 8—Directive Receiving Antenna of the Frame or Zigzag Type.

a direction broadside to the antenna causes, in the vertical elements, voltages which are all in phase. By alternately connecting the tops and bottoms of the vertical elements the wire currents caused by the signal voltages are also in phase and reinforce one another. The voltage and current relations for a broadside signal are shown in Figure 10.

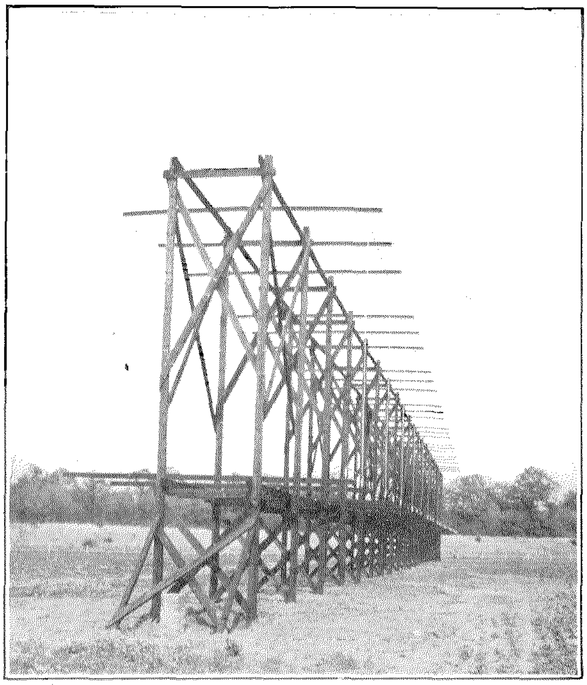

Figure 9—Zigzag Receiving Antenna.

A signal approaching end on to the array, however, produces an entirely different effect, since the incoming wave arrives progressively at each of the vertical members, producing out of phase disturbances. Hence the wire currents are likewise not in phase and cancel one another. Another advantage of this antenna is that the current distribution to a broadside signal is such that a current node is found in the center of each horizontal section. Thus there is no current flowing in the horizontal sections and hence no loss due to the resistance of the wire.

$$AB = MN = \frac{\lambda}{8} \qquad BC = CD = DE = FG = \frac{\lambda}{4}$$

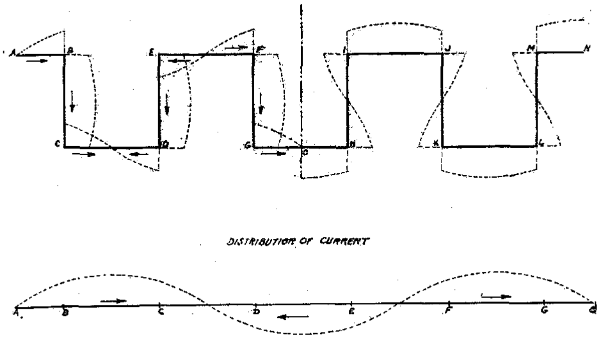

Figure 10—Distribution of Current and Voltage in a Frame or Zigzag Type of Antenna.

The antennas of this type constructed on the

Buenos Aires-Madrid link have a total length of structure of five and a half wavelengths. They deliver to the receiver a signal about 15 db. higher than a single vertical half wave antenna. The improvement in the ratio of signal to unwanted static is likewise about 15 db.

Figure 8 shows a method of connecting such an antenna to the receiver. An oscillating circuit LC is connected on one side to the antenna and on the other side to the reflector between voltage maximum points such as A and R in such a fashion that the length of wire AB connecting the point A to the oscillating circuit is $\frac{\lambda}{4}$ shorter than the length RD connecting the reflector to the point D of the oscillating circuit. This is to say:

$$RD = AB + \frac{\lambda}{4}$$

When a wave of length λ arrives in the direction of the arrow F, it induces in the antenna and reflector, currents separated in phase by $\frac{\pi}{2}$ since the distance between the antenna and the reflector is $\frac{\lambda}{4}$. Hence at points A and R, which are voltage maximums, there will be equal voltages but dephased by $\frac{\pi}{2}$. These currents in order to reach the oscillating circuit will require a time proportional to the distance. Since the distance RD is greater by $\frac{\lambda}{4}$ than the distance AB, the voltage coming from the reflector will lag an additional $\frac{\pi}{2}$ and the oscillating circuit LC will be excited at the points B and D by two voltages of the same character and amplitude but dephased by π. If V is an absolute value of the voltage between the points AR, the voltage acting on the oscillating circuit LC will be equal to 2V. It is possible to arrange a number of other types of couplings.

Appendix

The following is a mathematical derivation of the principles of directivity which were explained in general terms at the beginning of the paper.

Let A_1, A_2, $A_3 \ldots A_n$ be simple vertical antennas, placed in the same plane and constituting an antenna curtain (Figure 11). If these antennas are excited by currents in phase, the resultant field at a great distance from the curtain and in a direction perpendicular to the plane of the curtain, will be equal to the sum of the individual fields, namely n x h, h being the field strength of one antenna. In the direction P_1 at an angle of θ from the plane of the curtain, the fields emitted by each of the radiators remain equal, but the track traversed by the radiation is no longer equal. Between antennas A_1 and A_2 this difference A_1a_2 is equal to d cos θ. If this distance A_1a_2 is not negligible relative to the wavelength, the field emitted by the antenna A_2 will arrive at a point P_1 at a great distance from the antenna curtain dephased from the field of antenna A_1 by an angle equal to $\frac{2\pi d}{\lambda}$

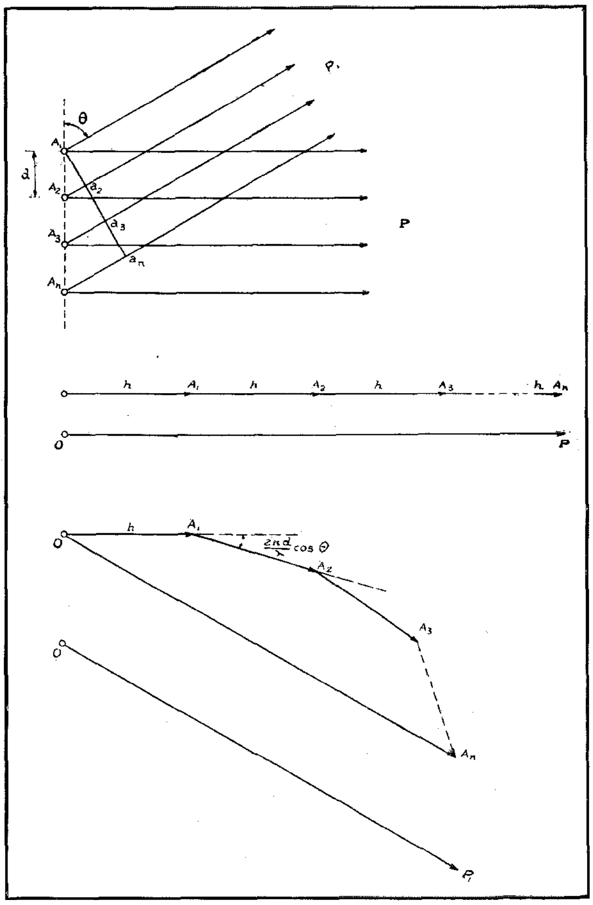

Figure 11—Directive Effect of Antenna Curtain.

$\cos \Theta$. An identical calculation can be made from the field of the antenna A_3, A_4, $A_5 \ldots . A_n$. The resultant field at a point P_1 will therefore be equal to a sum of n vectors, each dephased with respect to the preceding by an angle of $\frac{2\pi d}{\lambda} \cos \Theta$. The resulting vector O P_1 is always smaller than the vector O P, where P is a point in a direction perpendicular to the plane of the curtain. In certain directions of P the value of Θ will be such that the polygon OA_1, A_2, $A_3 \ldots .$ A_n will be a closed figure. In such a case the vector OP_1 equals zero and there is no radiation in this direction.

The absolute value of the resultant field in the different directions can be found by the following equation:

$$H = h \frac{\sin\left(n \pi \frac{d}{\lambda} \cos \Theta\right)}{\sin\left(\pi \frac{d}{\lambda} \cos \Theta\right)}$$

The direction of the maximum field is found at the angle $\Theta = 90^\circ$ and hence $H = n \times h$. In other directions the strength of the field will be less, sharpness of the ray depending on the total length of the curtain.

A process of reasoning entirely analogous can be developed for the directivity in a vertical plane. This directivity is obtained by a superposition of a certain number of antennas. It will be seen, therefore, that one can obtain an emission narrowly defined in both vertical and horizontal planes.

Terminal Equipments for Short Wave Point to Point Radio Links

By F. de FREMERY and P. R. THOMAS

International Telephone and Telegraph Laboratories, Incorporated

IN order to secure satisfactory operation from a modern radio link, it is necessary to supply at the ends of the link terminal equipment which shall not only provide the necessary circuit arrangements, but shall also provide means for controlling its technical performance. The arrangements necessary for speech transmission are dealt with in this article together with a brief description of the facilities for technical operation and control of the circuit.

The usual radio link connection consists of two one-way radio channels working in opposite directions. These two channels are inter-connected at either end by means of land lines to form a two-wire connection, which may be extended to any of the standard types of telephone systems.

The simplest form of such a system is shown in Figure 1, in which two terminal stations designated East and West are connected through land lines to the radio transmitting and receiving stations, A and D in the case of the East terminal, and C and B in the case of the West terminal. Speech from the radio transmitter A is received by the the radio receiver at B, and that from the transmitter C is received by the radio receiver at D. It will be seen, when considering the terminations at East and West, that this is a special case of a four-wire circuit. The difficulties peculiar to the operation of a circuit of this type are that the attenuation of the radio paths are variable and that speech transmitted from either radio transmitter may in certain cases be received by either of the radio receivers. In the case in which speech is transmitted through the East terminal and the transmitter at A, and received by the radio receiver at D, there will be formed a local loop including the terminating set, the lines connecting the terminating set to the radio stations and the short radio path between A and D. As the distance between the radio stations A and D may be small, the loss in this radio path would probably be very small when the radio wavelengths were the same or close together, and unless the network balancing the two-wire extension from the terminating set was exceptionally good, there would be singing round this local loop.

In cases where the attenuation in the radio paths A-B and C-D is small, and the balance of the lines and networks connected to the terminating sets at either end is not sufficiently accurate, there may be singing round the complete loop formed by the two uni-directional radio paths, their inter-connecting circuits and the terminating sets.

Anti-singing and Echo Suppressing Device

Even in the case when singing does not occur, the re-transmission of speech that passes across the hybrid coil at one end will appear as an echo at the other end. This echo will reduce the intelligibility and hence it should be suppressed.

The Bell Telephone Laboratories[1] have developed for prevention of singing and echoes in radio links a system which has been installed on the long wave transatlantic circuit between New York and London, and similar equipments have been designed for use on the short wave link between Madrid and Buenos Aires.

In order to prevent singing it is necessary to ensure that the attenuation round the whole loop shall always be greater than zero. The method of attaining this result is to arrange the circuit so that one or other of the paths is always inoperative. In the arrangement shown on Figure 1, a relay (a) is associated with the transmitting line which normally short circuits this line, thus preventing transmission and therefore singing round the loop. The amplifier detector is bridged across the transmitting line at some point before the short circuiting relay (a), and when speech enters the circuit the amplifier detector operates the relay (a) to remove the short circuit, thus allowing speech to be transmitted to the radio transmitter and so over the remainder of the circuit. In order to ensure that one of the paths is always blocked, a second relay (b) is arranged to be operated just before the relay (a) which removes the short circuit from the transmitting line; this second relay (b) short circuits the receiving line. In addition to these relays associated with the transmitting circuit there is an additional relay (c) associated with the receiving circuit to prevent the operation of the relay (a) controlling the transmitting circuit and relay (b) short circuiting the receiving circuit when speech is being received. This additional relay (c) is operated by an amplifier detector bridged across the receiving circuit at a point after that at which the line is short circuited during transmission. The equipment at either end of the four-wire circuit formed between the radio link and its interconnecting lines, is similar.

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[1] S. B. Wright and H. C. Silent, "The New York-London Telephone Circuit," *Bell System Technical Journal*, October, 1927.

The operation of the circuit is as follows:

In the normal condition when there is no speech on the circuit, both the transmitting paths are short circuited. Speech entering one end of the circuit clears its own transmitting path and short circuits the receiving path, thus preventing any disturbance entering the radio receiver and interfering with the talker or the apparatus controlled by his speech. The speech is transmitted over the radio link, received by the distant receiving station and enters the line connecting the receiver to the terminating set. This speech causes an amplifier detector to operate a relay (c) which prevents operation of the relays (a) and (b) controlled from the transmitting circuit.

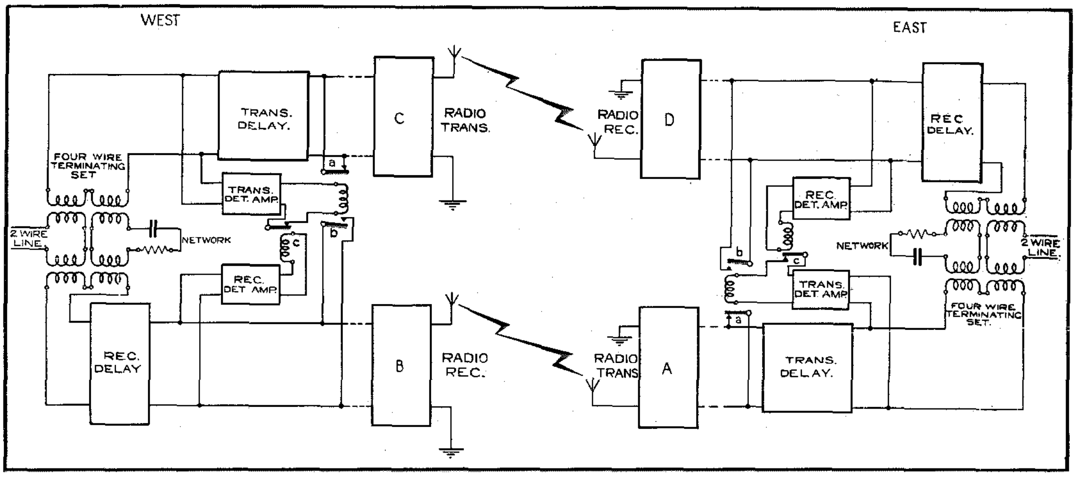

Figure 1—General Schematic of Complete Radio Link.

Amplifier Detectors and Delay Networks

As mentioned above, the speech to be transmitted has to clear its own path and unless this clearing operation can be performed instantaneously part of the speech will be lost. It is possible to design an amplifier detector and relay train which operates so quickly that, although the initial part of speech is lost, it is not possible to tell that the whole has not been transmitted. This involves the use of a very sensitive detector amplifier. In practice there is always a certain amount of noise associated with speech on land lines, and somewhat more noise on radio circuits. This noise limits the sensitivity at which the amplifier detector can be operated, since if the amplifier detector were very sensitive, it might either be held permanently operated or subject to false operation by noise. When a somewhat insensitive amplifier detector operates the relay to clear the transmitting path, there is noticeable clipping of the speech although the operating time of the combination is very small; the reason for this clipping is that the energy contained in the initial parts of speech may be very small and thus insufficient to operate the relays. The relays in this case do not start to operate until some time after speech has started and the amount lost is determined more by the characteristics of speech than by the operating time of the relays. One way of preventing this clipping of speech is to introduce between the input of the amplifier detector and the normally short circuiting relay, a network to delay the speech until after the relay has operated. The amplifier detector is then arranged so that it will not operate from the weak initial pulses of speech, but will operate when these have built up to some greater amplitude. The time lost during the building up of the speech currents is compensated for by the delay introduced by the network. By increasing the delay introduced and decreasing the sensitivity of the amplifier detector it is possible to arrange that only the peaks of speech shall be of sufficient amplitude to cause operation of the relays; the arrangement may then be subjected to noise, the amplitude of which approaches that of the peaks of speech, without false operation. A network having a delay of 20 or 30 milli-seconds is usually sufficient when dealing with the speech to noise ratios met with in a commercial circuit.

It has already been mentioned that the amplifier detector bridged across the receiving circuit is arranged to open the one connected to the transmitting circuit. This ensures that speech arriving at the radio receiver and passing across the terminating set into the transmitting circuit (owing to insufficient balance between the line and network) shall not cause false operation of the transmitting relays. It is necessary to make provision against false operation by noise occurring in the radio link, and the sensitivity of the receiving amplifier detector is thus limited. It is also necessary to ensure either that the amplitude of the received speech reaching the amplifier detector which controls the transmitting circuit shall be insufficient to operate the transmitting relay or that the relay controlled from the receiving side shall always be operated by the received speech.

The ratio of the speech energy available for the two-wire line to that reaching the transmitting amplifier detector depends on the accuracy with which the impedance of the balancing network simulates that of the two-wire line. Since speech may be required over a large variety of circuits it is impracticable to provide balancing networks to simulate the impedance of all such lines. It is therefore evident that only a small discrimination can be relied upon between speech received from the land line which it is required to transmit and received speech which it is not required to transmit.

Since a very sensitive amplifier detector connected to the receiving circuit may be falsely operated by noise currents, it is desirable to provide means whereby only currents approaching the peak values reached by speech shall operate the relays. The provision of a delay network in the receiving circuit between the receiving amplifier detector and the terminating set will allow time for the speech voltage applied to the receiving amplifier detector to rise to some considerable value before this speech, after passing through the terminating set, can reach sufficient amplitude to operate the amplifier detector connected to the transmitting circuit. The relays associated with the receiving circuit thus have time to operate and disable those connected to the transmitting circuit, without unduly increasing the sensitivity of the receiving amplifier detector and so increasing the risk of false operation.

As in the case of the transmitting delay circuit, the length of the receiving delay circuit is determined by the maximum speech to noise ratio with which good operation is required, with the modification that "clipping" is not important. The speech to noise ratio in the receiving circuit is usually considerably worse than that in the transmitting circuit and for this reason it is desirable to make the receiving amplifier detector somewhat less sensitive than the detector transmitting amplifier. The first condition would lead to a delay network having a delay approximately equal to the operating time of the relay which is less than 5 milliseconds. In practice it is found that from 5 to 10 milliseconds delay with a less sensitive amplifier detector will switch any circuit which, from a talking point of view, has a speech to noise ratio within commercial limits.

Gain Control

The introduction of variable attenuators either side of the terminating set allows some discrimination to be obtained between the speech received from the radio receiver and that from the two-wire extension. The discrimination obtained depends on the effective loss between the receiving and transmitting amplifier detectors. Thus with any given condition of balance between the line and the network connected to the terminating set, the sum of the added losses must have some minimum value. The level of speech arriving from the line determines the setting of the transmitting attenuator, since this attenuation loss must be adjusted to load fully the radio transmitter. The loss in the receiving side is adjusted either to give a suitable output level or to the minimum value determined by the other conditions; the latter case only being necessary under bad noise conditions on the radio circuit.

Circuit Arrangements

Figure 2 shows the arrangement of the terminal equipments at Madrid and Buenos Aires in some detail. It will be seen that the two-wire extension is connected through an ordinary four-wire terminating set to the apparatus associated with the transmitting and receiving lines. Considering first the apparatus in the transmitting line, there is a gain control panel associated with a volume indicator, so that the technical operator can change the amplification in this circuit to keep the level of speech delivered to the line for the radio transmitter constant and sufficient to load fully the radio transmitter. The output of this gain control panel is connected to the input of one side of a four-wire repeater whose gain is so adjusted that its output shall be that required by the interconnecting line to the radio transmitter. Across the output of this repeater is bridged the input of the transmitting amplifier detector, which controls the relays associated with the transmitting path and the relay for short circuiting the receiving path. Next comes the transmitting delay network with its equaliser, low pass filter to limit the upper frequency to be transmitted, and repeater for compensating its attenuation at various frequencies. Next two repeating coils which include the short circuits which is normally on the transmitting path for the prevention of transmission when there is no speech. The privacy equipment is located between these repeating coils and the line to the transmitting station.

At the receiving side of the circuit the line from the radio receiver is connected to one half of a four-wire repeater adjusted to increase the received level to that required for the operation of the equipment, and thence through the privacy equipment to a coil group which is arranged in connection with a relay panel to perform the switching operation. This coil group is connected to the receiving delay network and at the junction of these is bridged the receiving amplifier detector. The receiving delay network is associated with an equaliser and a repeater as in the case of the transmitting delay network and is then connected through a gain control panel and repeater to the four-wire terminating set.

It will be noticed that each separate part of the circuit is associated with a repeater. The object of this is to make both the delay network and privacy system each have zero attenuation, thus making it possible for them to be patched out of the circuit without affecting the transmission characteristics of the whole.

Voice Operated Relay Circuits

The relay switching is arranged in each case so that the break of the switching relay performs the switching operation. This reduces the operating time of the switchgear and thus minimises the lengths of the delay networks necessary for a given amplifier detector sensitivity. From the transmitting side transmission is normally prevented by the use of a short circuit, and the break of the relay will remove it. In the receiving side, however, the circuit is normally in the transmitting condition and it is required to interrupt transmission by breaking contact. From considerations of balance it is undesirable to break the circuit. To avoid this, two repeating coils are connected into this circuit, as shown on Figure 3. It will be seen that when the relay contact is made, these repeating coils are so connected that their windings are in series aiding, with their centre points joined. When the contact is broken the connection between the centre points is

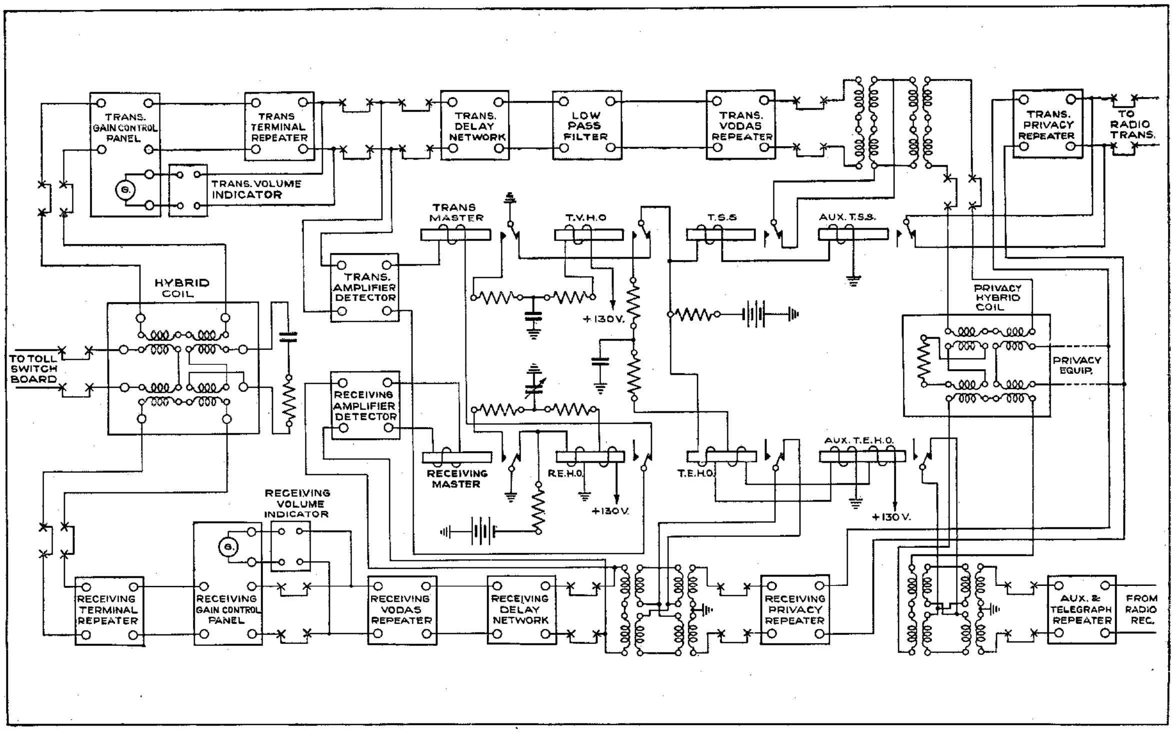

Figure 2—Terminal Equipments at Madrid and Buenos Aires.

severed and the windings of the coils are in series but opposing one another, so that the transmission of currents from one coil to the other is prevented.

Speech entering the terminating set from the two-wire side enters the transmitting half of the amplifier detector and operates the transmitting master relay. When the armature of this relay leaves its back contacts, relays TEHO[1], Aux. TEHO[2], TSS[3] and Aux. TSS[4] operate; when this armature makes its front contact relay TVHO[5] operates. The operation of relay TEHO puts the coil group in the receiving circuit in a non-transmitting position. The operation of relay TSS removes the short circuit from the transmitting side and the operation of relay Aux. TSS removes a similar short circuit beyond the privacy equipment. During the operation of these relays speech has been traversing the transmitting delay network and can then pass through the remainder of the circuit and the privacy equipment to the radio transmitter. The receiving circuit is disabled between the radio receiver and the receiving amplifier detector, thus preventing either operation of the amplifier detector or interference of the talker by currents from the radio receiver.

The release of the relays operated by the transmitting master relay is controlled by the charge of condensers through resistances. The condensers and resistances associated with the contact of the transmitting master relay and the winding of the relay TVHO control the release time of relay TVHO which in turn controls the release of the TSS and TEHO relays. The TSS relays release immediately after the TVHO relay reaches its back contact, but the release of the TEHO relay is held up during the charging period of a condenser resistance circuit, thus ensuring that the transmitting path is blocked before the receiving path is opened.

The release time of the TVHO relay is so arranged that it will hold during pauses between words to reduce the number of times the circuit is switched during talking from this terminal. This relay must, however, release sufficiently early to prevent clipping of the reply. Since the total transmission time of the circuit determines the time which elapses before a reply can arrive it is safe to make the TSS relay hold up for twice this time, thus allowing for the last word to reach the distant station and an instantaneous reply to return.

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[1] TEHO indicates Transmitting Echo Hangover.

[2] Aux. TEHO indicates Auxiliary Transmitting Echo Hangover.

[3] TSS indicates Transmitting Singing Suppressor.

[4] Aux. TSS indicates Auxiliary Transmitting Singing Suppressor.

[5] TVHO indicates Transmitting Voice Hangover.

After speech in the transmitting path has ceased and the relays have released, speech may enter the receiving path and the receiving amplifier detector and operate the receiving master relay. The armature of this relay on leaving its back contact causes the REHO[6] relay to operate and break the connection between the transmitting half of the amplifier detector and the transmitting master relay, thus preventing the speech operating this relay and the relay train controlled by it. The release time of the REHO relay is controlled by the charging of condensers which have previously been discharged by the action of the receiving master relay making its front contact. This release time is adjusted to take care of echoes in any circuit which may be connected to the two-wire side of the four-wire terminating set. The relay circuits shown on Figure 2 include only the operating connections and do not include either biassing windings or testing circuits.

The relays used in this equipment are all polarised telegraph relays of the same type which are very sensitive and operate quickly. A special panel is provided for adjusting these relays.

Switching of Privacy Equipment

The circuit is arranged to operate with a single privacy equipment which can be used alternatively in the transmitting and receiving sides since the system is always in a one-way condition. This assumes that the privacy systems at the two ends are complementary. Figure 2 shows the transmitting and the receiving circuits connected to the opposite sides of a hybrid coil arrangement, the network terminals being closed through 600 ohms. and the input of the privacy equipment being connected to the line winding. The output of the privacy equipment is connected to both transmitting and receiving circuits.

In the normal condition the transmitting circuit on both sides of this connection is short circuited by the TSS and the Aux. TSS relays, speech can then enter the privacy equipment from the receiving circuit and pass through the hybrid coil back into the receiving circuit without interfering with the transmitting circuit or being subjected to interference from this circuit.

In the transmitting condition the TSS and Aux. TSS relays are operated to remove the short circuits from the transmitting path. The TEHO and Aux. TEHO relays are also operated and prevent transmission from the receiving circuit entering the privacy equipment, and also prevent transmission from the privacy equipment to the remainder of the receiving circuit. Speech from the transmitting circuit can then pass through the privacy equipment to the radio transmitter.

It will be noticed that a repeater is placed between the output of the privacy equipment and the short circuit on the transmitting line to prevent this short circuit being directly on the output of the privacy equipment. A similar repeater is also used in the receiving circuit. The necessity of having a repeater in the transmitting circuit to isolate the privacy equipment from the short circuit, renders it impossible to include one repeater in the privacy equipment instead of one in each line.

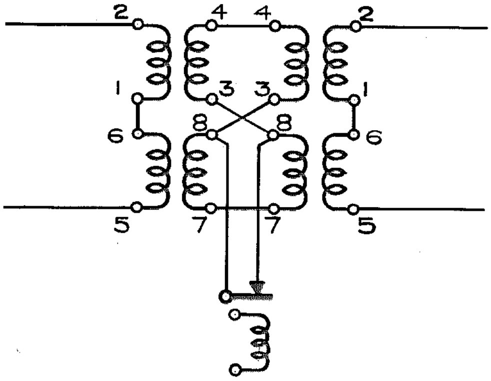

Figure 3—Special Coil Group for Receiving Circuit.

Monitoring and Control

The equipment for the switching and the control of the circuit is arranged with suitable monitoring apparatus. A technical operator monitors continuously on the circuit and adjusts the gain controls and amplifier detector sensi-

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[6] REHO indicates Receiving Echo Hangover.

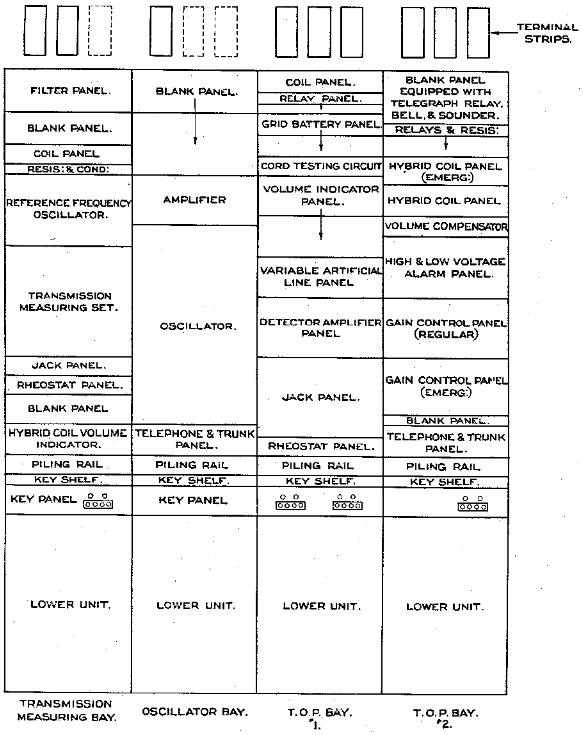


Figure 4—Technical Operator's Position—Front Equipment.

tivities to give the best service obtainable at any moment. The two-wire line is connected through to jacks on an operating position in a toll exchange and traffic is handled in a similar manner to that adopted on ordinary toll circuits.

Equipment

The terminal equipment apparatus is grouped on two racks, one comprising all the panels which require adjustment is known as the Technical Operator's Position, and the other is equipped with the voice operated apparatus and known as the V. O. D. A. S. rack. The privacy apparatus is grouped on a special rack and forms a complete unit apart from the terminal equipment.

Figure 4 shows the technical operator's position. It consists of four bays. The two bays on the left are equipped with transmission measuring apparatus and the two bays on the right comprise the gain control panels, amplifier detector panels and volume indicators, telephone and trunk panel, etc. By means of this apparatus the technical operator can monitor on the circuits at various points and has all important controls within easy reach for making the adjustments required for optimum performance of the system under prevailing conditions.

From the technical operator's position order wire circuits run to the toll switchboard, toll testboard, the radio transmitting station and the radio receiving station, so that the technical operator can readily communicate directly with all operators and attendants at important points on the circuit. He can also communicate with the home as well as with the distant subscriber.

Figure 5 shows the V. O. D. A. S. rack, comprising a battery supply bay, delay network bays and a bay containing the voice operated switching arrangements with their testing apparatus. The relay testing apparatus comprises a testing and adjusting panel for the polarised telegraph relays and an echo suppressor testing panel for testing the operating hangover times of various relay trains.

Jack fields are provided on both the technical operator's position and V. O. D. A. S. rack. These jack fields permit easy testing of parts of the circuits and afford means by which the circuits can be modified to meet special requirements.

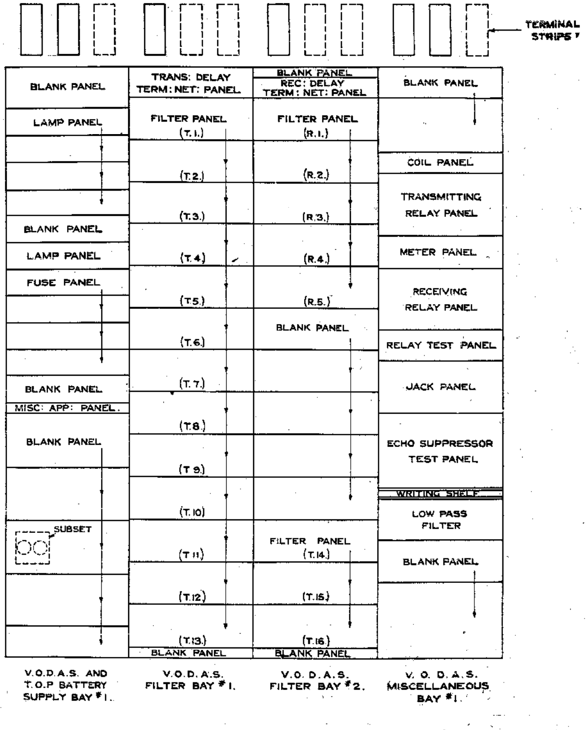


Figure 5—V. O. D. A. S. Rack—Front Equipment.

Inauguration of Madrid-Buenos Aires Radio Telephone Link

By FRED T. CALDWELL

Chief Engineer, International Telephone and Telegraph Corporation (España)

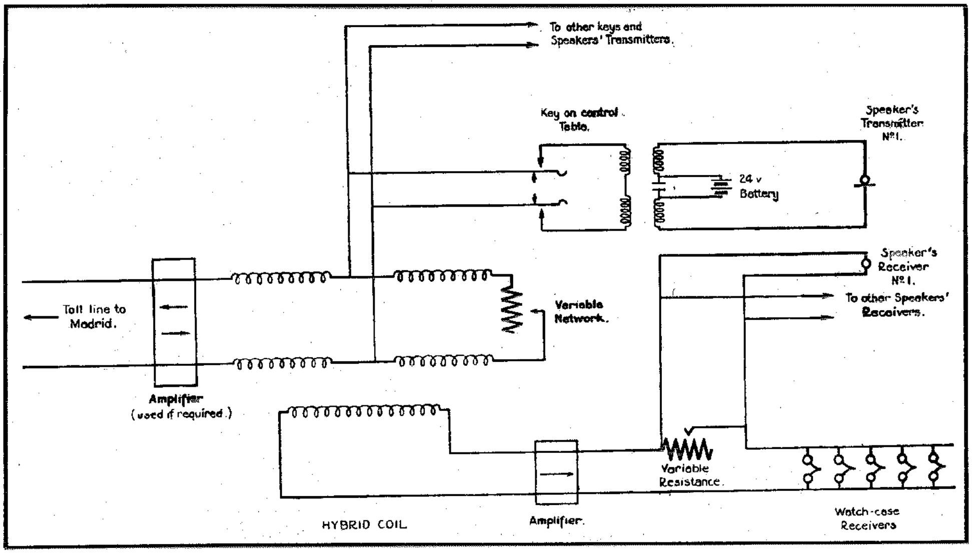
THE telephone service over the new Madrid-Buenos Aires radio link was officially inaugurated on October 12th, 1929. This date was peculiarly fitting for a ceremony of this nature, since it marks the "Fiesta de la Raza," on the occasion of which the Spanish speaking peoples on both sides of the ocean celebrate their common racial origin. On this day many high officials of the Spanish Government and diplomatic representatives of the Latin-American republics had gathered at Seville to take part in celebrations organized in connection with the Ibero-American Exposition, held in this historic city.

The programme of the inaugural ceremony involved an interchange of greetings between speakers in Seville and Buenos Aires, followed by similar conversations between Seville and Montevideo (Uruguay). Arrangements were also made so that a considerable number of guests in Seville, Buenos Aires and Montevideo could listen to the conversations of the speakers.

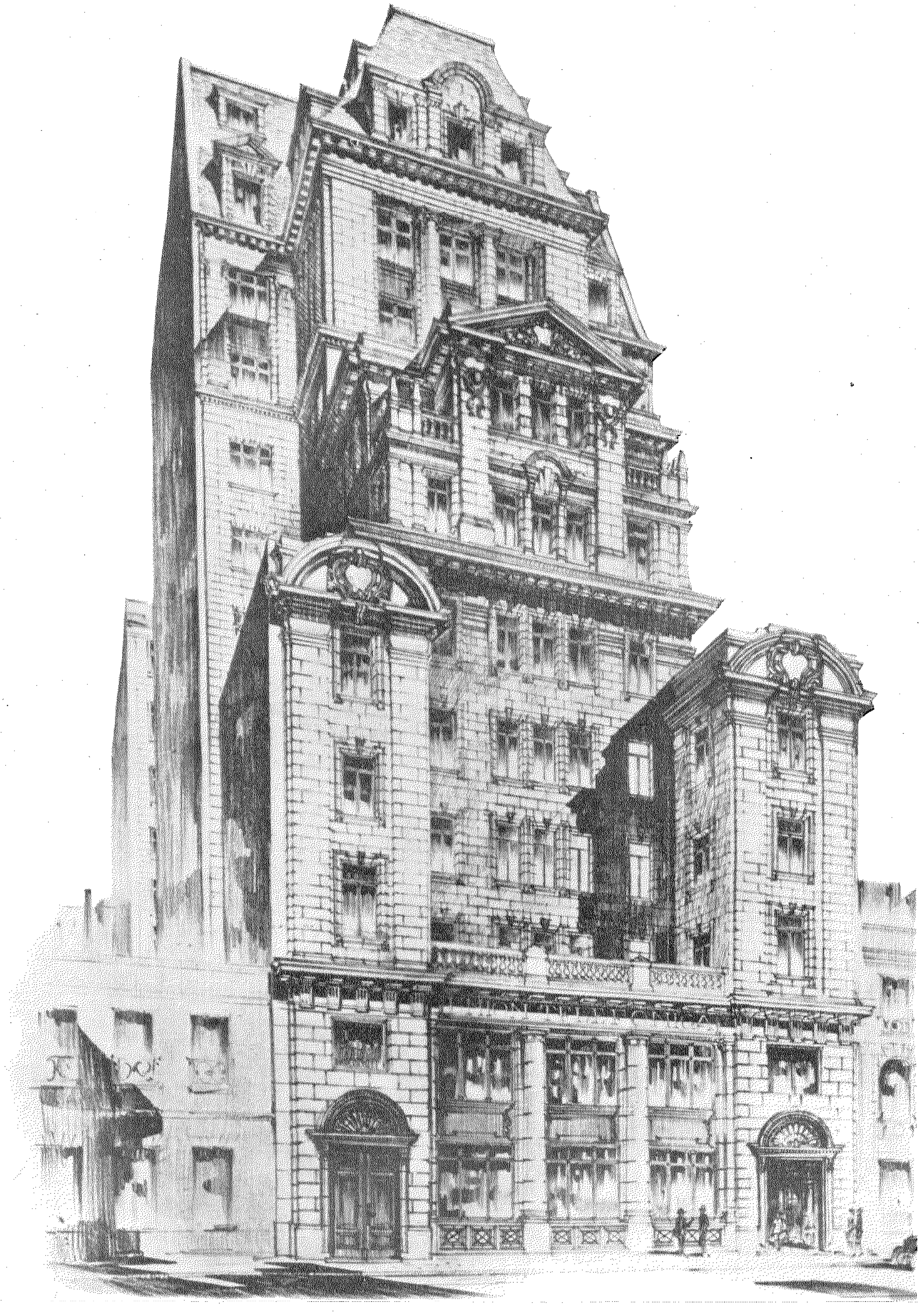
The set-up at the Spanish end of the radio link involved the use of four telephone circuits between Madrid and Seville which were employed in the following manner:

Two carrier telephone channels were extended in Madrid from the toll test board to the technical operator's position in the radio terminal room. From the toll test board in the Seville toll office these circuits were extended over pairs in the trunk cable to the control table located in the Exposition sub-exchange, about one and a half miles from the toll office, where the demonstration was held. One of these circuits was used to extend the radio communication for the speakers; and facilities were provided at the control table in Seville and at the technical operator's position, so that in case of trouble on this circuit the communication could be switched instantly to the second.

In addition to these two circuits, which may be designated respectively as the regular and relief talking circuits, two order wires were established, using physical toll circuits. One of these order wires was set up to connect a telephone located on the control table at Seville directly with the Madrid technical operator's



Partial schematic of the Spain-Argentina-Uruguay telephone service.



Headquarters of the United River Plate Telephone Company, Ltd., Buenos Aires, where press representatives and Company officials participated in the inauguration of Spanish-South American telephone service.

Seville.—Presiding table at the opening of the transatlantic telephone service Spain-Argentina and Spain-Uruguay. From left to right: Mr. Lewis J. Proctor, Executive Vice-President; His Excellency Daniel García Mansilla, Argentine Ambassador to Spain; General Miguel Primo de Rivera; H. R. H. the Infante Don Carlos, Military Governor of Seville; His Excellency Cardinal Ilundain, Archbishop of Seville; His Excellency Benjamin Fernández y Medina, Minister of Uruguay to Spain, and Mr. José Cruz Conde, Director of the Ibero-American Exposition.

position, and was also bridged in to the Madrid toll test board. This circuit was used by the engineers in charge of the control table and the technical operator's position, to coördinate the connection and switching of the talking circuits.

The other order wire was set up between the toll test board at the Seville toll office and the Madrid toll test-board, and during the demonstration attendants were bridged across this line at Córdoba and Ciudad Real, where the repeater stations on the Madrid-Seville toll lead are located. The object of this circuit was to facilitate maintenance of the talking circuits during the course of the demonstration, and was used for giving directions to the attendants at the above mentioned repeater stations.

The equipment installed at the Exposition sub-exchange in Seville, where the demonstration was held, consisted of seven desk type telephones of the latest International Standard Electric design for use by the speakers, and a bank of 75 watch-case receivers for the guests. The transmitters of the speakers' telephones were wired individually to the control table and arranged so that the engineer in charge of this position could connect any one of them at will to the talking circuit, thus eliminating any possibility of interruption to the speeches. The receivers of the speakers' telephones were connected in the same circuit as the watch-case receivers and the entire receiver bank was arranged so that the talking circuit could be connected to it at the control table through an amplifier. The gain of this amplifier was regulated from the control table.

The manner of connecting the receiver banks and the speakers' telephones to the talking circuit is indicated in the circuit schematic. It is evident that with this arrangement the volume levels in the different parts of the circuit could be adjusted independently. It was considered desirable that the guests using the watch-case receivers at Seville should hear the local speakers at a volume level equal to or slightly less than that of the incoming speech, and this condition was easily secured by regulating the impedance of the terminating network to a point which would give just sufficient unbalance in the hybrid coil to provide the desired level in the receiver bank when one of the speakers' transmitters was in use.

The receivers of the speakers' telephones were connected across a variable resistance in the manner shown, instead of being connected directly in parallel with the watch-case receivers, so as to compensate for the lower impedance of these receivers as compared with the watch-case receivers.

At the South American end of the link the set-up was more complicated, since in Buenos Aires the guests and speakers were divided into two groups located in separate buildings and, in addition, arrangements were necessary for extending the communication to Montevideo on the termination of the inaugural ceremony at Buenos Aires.

The main control table was located in the radio terminal room in the toll office of the United River Plate Telephone Company, Limited,

Official opening of the telephone service between Argentina and Spain.—Government House in Buenos Aires. From left to right: standing, Messrs. Valenzueala, Assistant Secretary of Foreign Relations; Benard, Manzano and Auzón. Seated, His Excellency the Minister of Foreign Relations, Dr. Horacio Oyhanarte; His Excellency the Minister of the Interior, Dr. Elpidio González; His Excellency the Spanish Ambassador, Mr. Ramiro de Naeztu. Seated, with their backs to the camera: Dr. Alfredo Martinez and Mr. Alejandro Funes Lastra, Assistant Director of Posts and Telegraphs.

Patio of the pavilion of the Compañia Telefónica Nacional de España, Ibero America Exposition, Seville, at the opening of the Spain-Argentina-Uruguay Telephone service.

in Buenos Aires, and provision was made for connecting either individually or simultaneously to the demonstration set-ups in Buenos Aires and Montevideo.

The Argentine and Spanish officials who took part in the demonstration were gathered at the Casa Rosada, or Government House, in Buenos Aires, where four telephones and sixteen watch-case receivers were installed for their use. The President of the Buenos Aires Press Association who was one of the speakers on the programme, and the majority of the guests, met at the Telephone Company's headquarters building where one hundred watch-case receivers were provided in addition to the speakers' telephones.

For the inaugural ceremony with Uruguay, sixty watch-case receivers were installed in the Government Palace at Montevideo, together with the usual arrangements of control table and speakers' telephones.

The circuit connecting Montevideo with Buenos Aires was one of those recently provided to give telephone service between the two capitals. This communication consists of a submarine cable some fifty kilometers in length, between Buenos Aires and Colonia, connecting at the latter point with land lines to Montevideo. The distance from Colonia to Montevideo is 223 kilometers, making the total length of the Buenos Aires-Montevideo circuit almost three hundred kilometers.

The switching operations and maintenance of circuits involved in the demonstration were controlled by means of an order wire connecting the Government House, the demonstration room in the Company building, and the radio terminal room in Buenos Aires with the Colonia repeater station, and the toll office and Government Palace in Montevideo.

The ceremony was scheduled for 6 o'clock, Greenwich time, on the afternoon of October 12th. Shortly before this hour the communication was established, and the engineers in charge of the control tables at Seville, Buenos Aires and Montevideo conversed with each other and made final tests of the entire circuit set-up.

At the appointed hour the speakers and guests were seated in their places and the circuit was connected in Seville and in Buenos Aires to the telephones of the masters of ceremonies at the speakers' tables. Mr. Proctor, Vice President of the International Telephone & Telegraph Corporation, acting as master of ceremonies in Seville, opened the demonstration by addressing Captain Rock, Secretary of the International Telephone & Telegraph Corporation, who was acting as master of ceremonies at Buenos Aires, in the following terms:

"Good afternoon, Captain Rock; this is Seville, Mr. Proctor speaking."

Captain Rock answered:

"Good afternoon, Mr. Proctor; this is Buenos Aires, Captain Rock speaking."

Mr. Proctor then continued:

"Captain Rock, I am greeting you in the presence of His Highness the Infante Don Carlos, General Primo de Rivera, President of His Majesty's Government, His Eminence the Cardinal Archbishop of Seville, and other distinguished guests."

Captain Rock replied:

"I greet you in the presence of His Excellency Dr. Elpidio Gonzalez, Minister of the Interior of the Argentine, Dr. Horacio Oyhanarte, Minister of Foreign Affairs, and other distinguished guests, and I now have the honour of turning over the circuit to His Excellency the Minister of the Interior."

At this point the engineers at the control tables switched the circuit to the proper telephones, and General Primo de Rivera addressed the Argentine Minister of the Interior who replied in turn. Speeches were then exchanged between General Primo de Rivera and the Spanish Ambassador in Buenos Aires, the Argentine Ambassador to Spain and the Minister of Foreign Affairs of Argentina, and the Director of the Seville Exposition and the President of the Buenos Aires Press Association.

Before each of these speeches the circuit was connected to the telephones of Mr. Proctor and Captain Rock, who introduced the speakers.

Following the exchange of speeches between the Director of the Seville Exposition and the President of the Buenos Aires Press Association, Mr. Proctor again spoke, declaring that the inaugural ceremony for telephone service between Spain and the Argentine was finished and that this service would be open to the public as soon as the inauguration ceremony with Uruguay had been effected. Mr. Proctor concluded his remarks by requesting Captain Rock to extend the circuit to Montevideo. Captain Rock replied that he would immediately have the circuit extended to Montevideo.

At this point the circuit was switched through from Buenos Aires to Montevideo and so quickly was this operation effected that many of the listeners were taken by surprise when they heard Mr. Hodges, acting as master of ceremonies in Montevideo, say:

"Good afternoon, Mr. Proctor, this is Montevideo speaking."

This second ceremony was effected in a manner exactly similar to the first, speeches being exchanged after introductions by Mr. Proctor and Mr. Hodges, between the President of the Spanish Government, General Primo de Rivera, and the Minister of Foreign Affairs of Uruguay, General Primo de Rivera and the Minister of Spain in Uruguay, the Minister of Uruguay in Spain and the Minister of Foreign Affairs of Uruguay, and finally the Director of the Seville Exposition and the President of the Press Association of Montevideo.

Mr. Proctor and other Telephone Company officials present received most cordial greetings from all of the high officials and other guests on the success of the demonstration, the precision with which it had been executed, and the remarkable clarity with which the speeches in both directions had been heard.

Following the ceremony the service between Spain and the Argentine and Uruguay was declared open to the public and an opportunity was afforded to the various representatives of the press who were among the guests at Seville, Buenos Aires and Montevideo to converse over the circuit. These conversations continued for a considerable time and the speakers were enthusiastic in their praise of the facility which this radio telephone link affords them.

Since the demonstration, the circuit has been available for commercial traffic. The operating method followed is somewhat similar to the despatch method, there being a line operator and two report operators at each end of the circuit. The line operators remain cut-in on the circuit at all times. Between conversations they pass orders and reports over the circuit and they are responsible for connecting subscribers to the circuit in turn and timing the conversations. The timing is done by means of a stop-watch and allowance is always made when the subscribers have any difficulty in understanding one another.

The report operators occupy positions adjacent to the line operator on the left and right and are responsible for passing reports to the subscribers and preparing them for connection to the circuit.

Up to the present this service is available only to Spain, the Argentine, and Uruguay, but it is planned before long to extend the service to other countries in Europe and South America. The importance of this telephone link can readily be appreciated when one considers the extensive commercial relations existing between Spain, Great Britain, France and other European countries on the one hand and the great republics of South America on the other hand.

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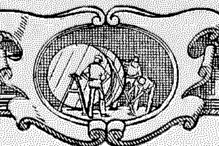

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CONTENTS

The New York-Buenos Aires Radio Circuit.........259
By H. H. Buttner

Progress in Subscribers' Transmission Apparatus....265
By L. C. Pocock, M.Sc., A.M.I.E.E., A.C.G.I.

A System of Electrical Transmission of Pictures....283
By Yasujiro Niwa

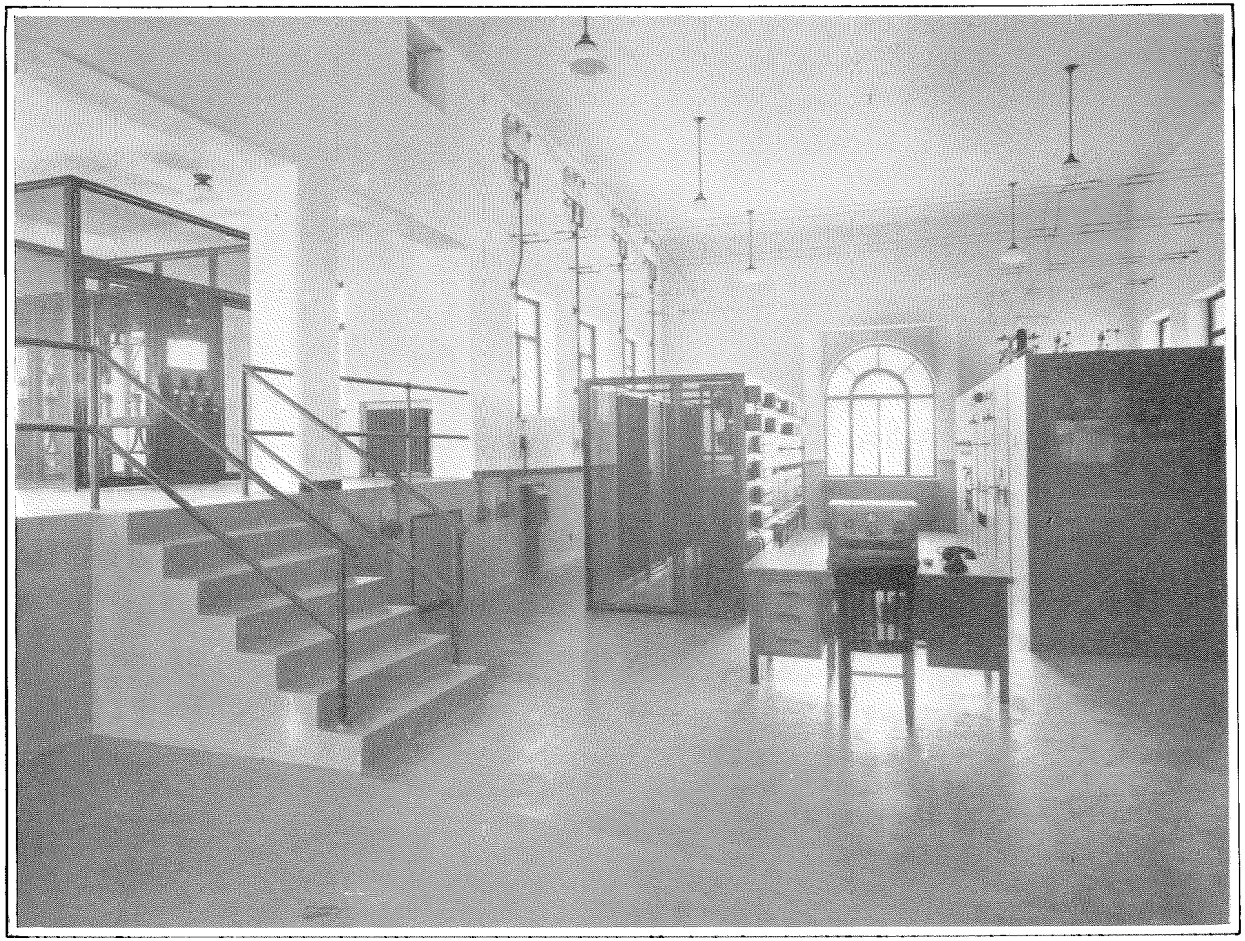
Rapid Toll, Suburban and Rural Automatic Telephone Services in Tuscany...........................296
By L. A. Zanni

Voice Frequency Dialling: Field Trial and Demonstration in Italy of Four Frequency Toll Signalling System.................................306

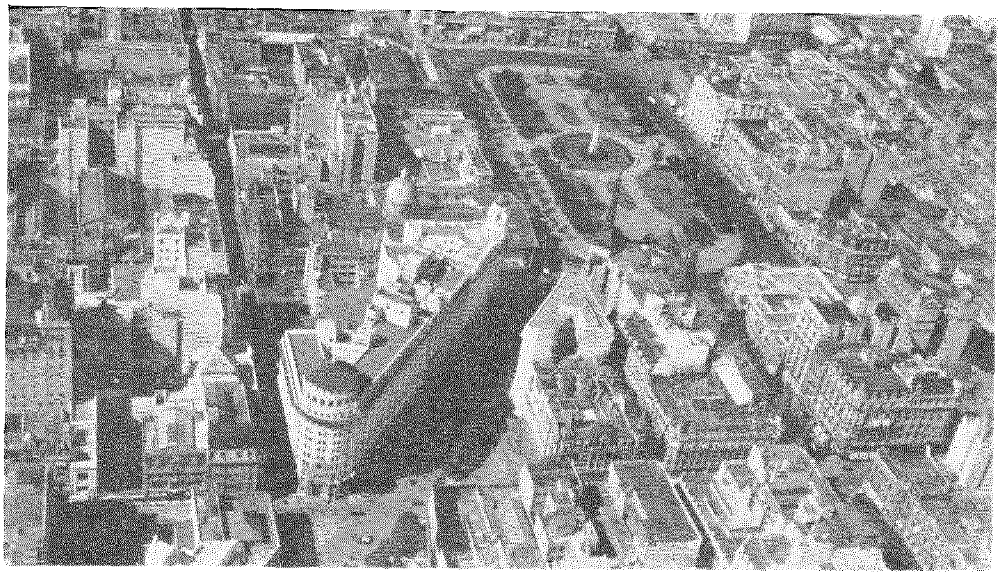
Power Plant for Unattended Automatic Telephone Exchanges....................................309
By E. Wollner

An Electrical Frequency Analyzer.................315
By Masatsugu Kobayashi

The Determination of the Desirable Attenuation-Frequency Characteristic of a Long Toll Circuit 320
By A. R. A. Rendall



Transmitter Room at Hurlingham, Buenos Aires-New York Circuit



Plaza de Mayo, Buenos Aires, Argentina.

The New York-Buenos Aires Radio Circuit

By H. H. BUTTNER

Assistant Vice President, International Telephone and Telegraph Corporation

THE opening of the radio circuit between New York and Buenos Aires on April 3rd, connecting 277,000 telephones in Argentina, Uruguay, and Chile with 21,600,000 telephones of the United States, Canada, Mexico, and Cuba, marks another step in the world wide linking of the people of the earth by means of telephonic communication. By means of the transatlantic radio telephone between New York and London, the Buenos Aires-Madrid radio telephone described in this journal in February, and now the New York-Buenos Aires radio telephone, the telephone networks of three continents are in actual or potential communication with one another. The New York-Buenos Aires link is unique in being the first two-way telephone circuit between North and South America. Like the New York-London, and Madrid-Buenos Aires, it is a true radio telephone trunk link giving service, not to special booths in the cities where the terminals exist but to the entire telephone networks of the countries concerned.

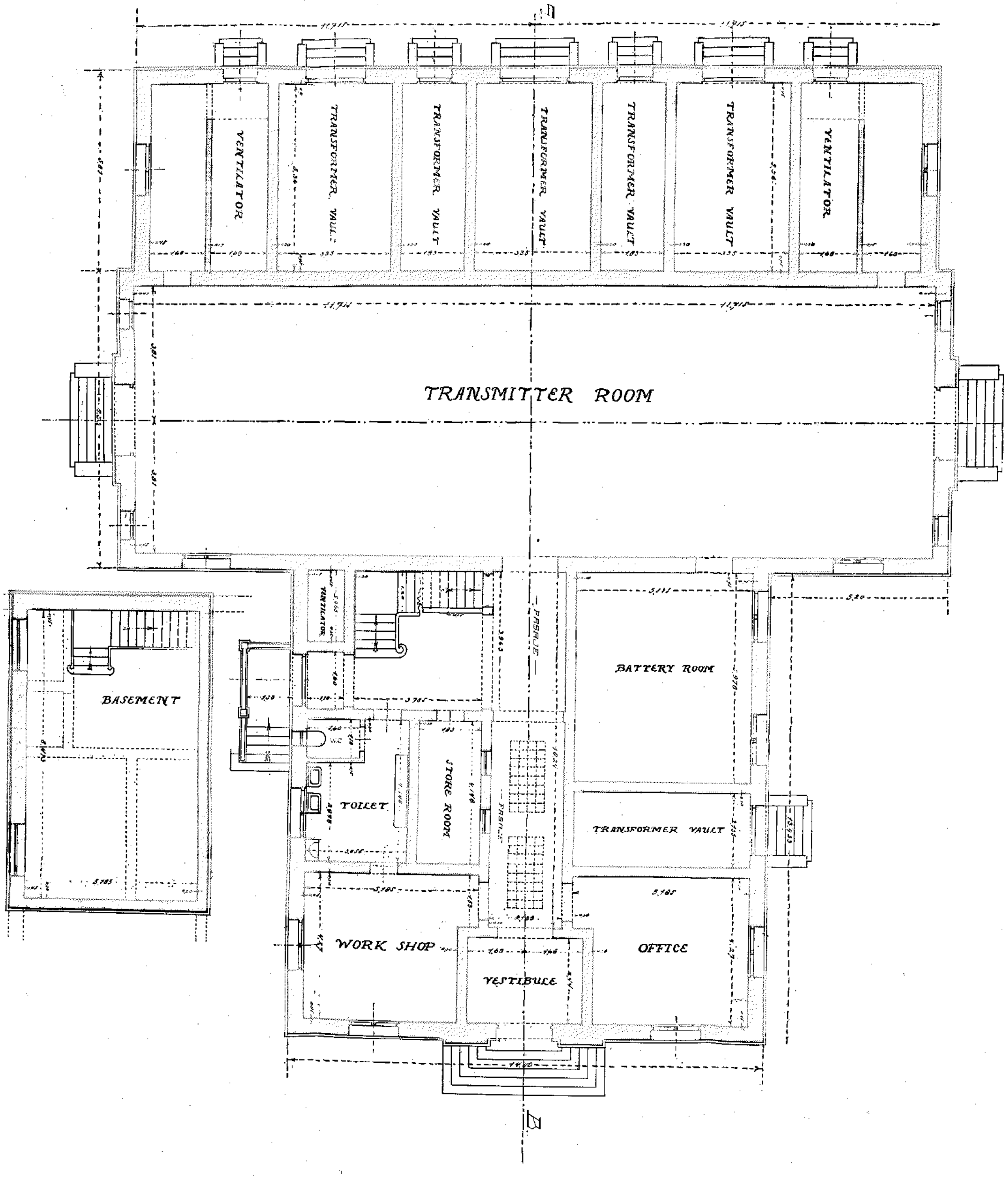
Since the theory of operation of short wave radio telephone links was described in some detail in the recent February edition of *Electrical Communication* on the Buenos Aires-Madrid link, it is proposed in this paper to point out only in a general way the features of special interest.

The radio terminals are located near Buenos Aires and New York. At Buenos Aires the transmitting station is at Hurlingham, adjacent to the transmitter for the Buenos Aires-Madrid circuit, while the receiving stations for both the Madrid and New York services are at Platanos. The New York terminal is operated by the American Telephone and Telegraph Company and is located near the short wave transatlantic circuit terminals; the transmitter at Lawrenceville, N. J., and the receiver at Netcong, N. J. The distance between the New

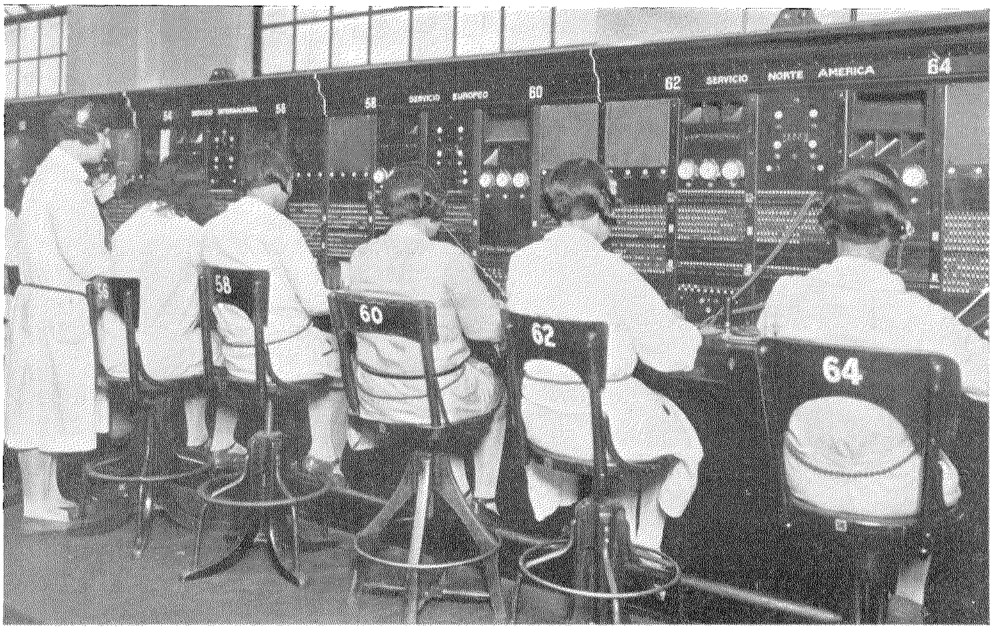
York and Buenos Aires terminals is approximately 8,522 kms. (5,290 statute miles).

Transmitter

The transmitter at Hurlingham is located in a building especially designed to house it. On the ground floor and extending the full width of the building is a large room which contains the motor generator sets. Directly above this room is another of the same dimensions contain-

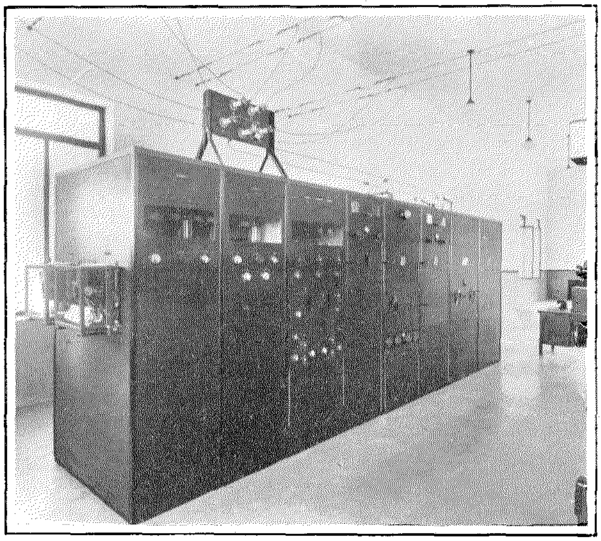


Plan of Transmitter Building.



International Service Toll Board—
Buenos Aires-New York
Buenos Aires-Madrid
Buenos Aires-Uruguay and Chile

Transmitter Building at Hurlingham, Rear View

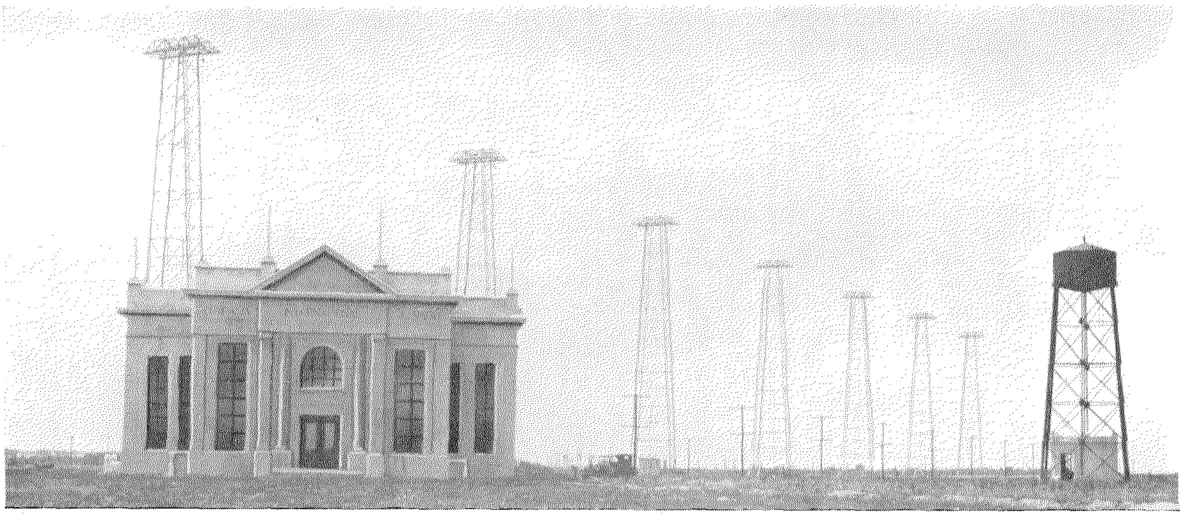


Transmitter at Hurlingham, Buenos Aires-New York Circuit

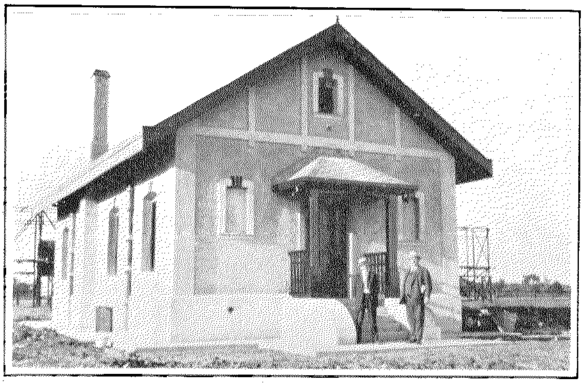
ing the power board and radio transmitter proper. On the ground floor adjoining the power room, are a series of vaults containing high voltage transformers and water cooling units. A vacuum tube rectifier for supplying high voltage to the transmitter is located above the transformer vaults in a small room opening into the main transmitter room. The building is designed for an ultimate of two transmitters.

The transmitter is of Western Electric manufacture. It is of the crystal controlled master oscillator type and electrically corresponds closely with the Madrid transmitter described in the February edition of *Electrical Communication.* The output stage of the transmitter consists of six water-cooled tubes in push pull and delivers 15kw. to the antenna on the highest frequency of approximately twenty-one megacycles (14.3 meters). The installation is especially noteworthy for the precautions taken to insure continuity of service and safety to the operating personnel. Motor generators and power transformers are all supplied in duplicate and so interconnected that in case of failure, any piece of power equipment can be almost instantaneously replaced by spare equipment by throwing a switch. Safety to the personnel is provided by an interlocking system which associates mechanical key operated locks with all switch operating handles and vault inclosure doors. A certain key or series of keys is required to enter any enclosure containing dangerous potentials. The opening of switches, which remove the dangerous voltages from the enclosure in question, releases keys which may be used to open the door. Only when all voltages are shut off and all keys released can the enclosure be entered.

The transmitting antennas employed were described in some detail in the paper, "Short



General View of Transmitter Building at Hurlingham, Buenos Aires-New York Circuit

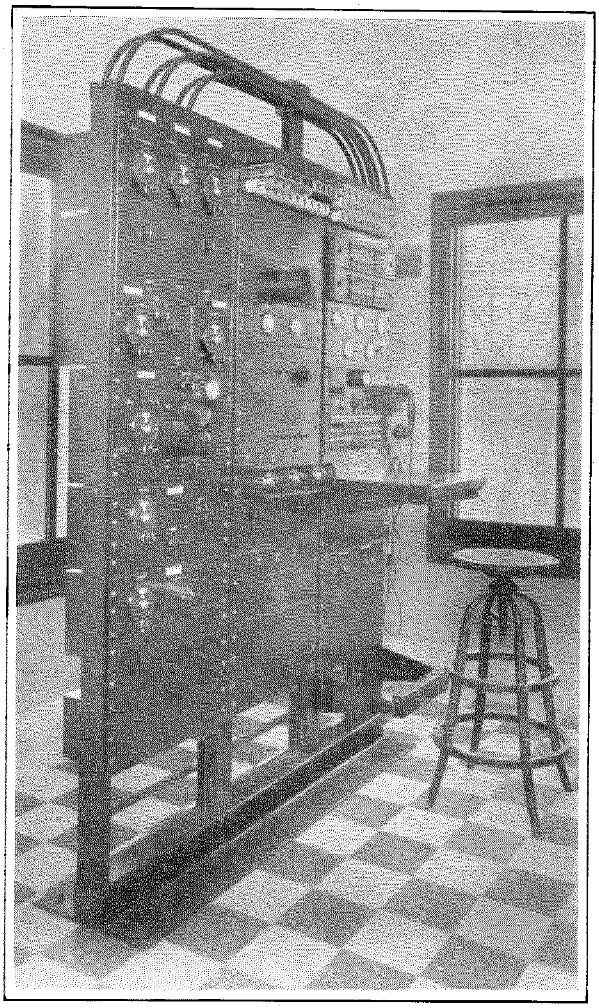


Receiving Building at Platanos, Buenos Aires-New York Circuit

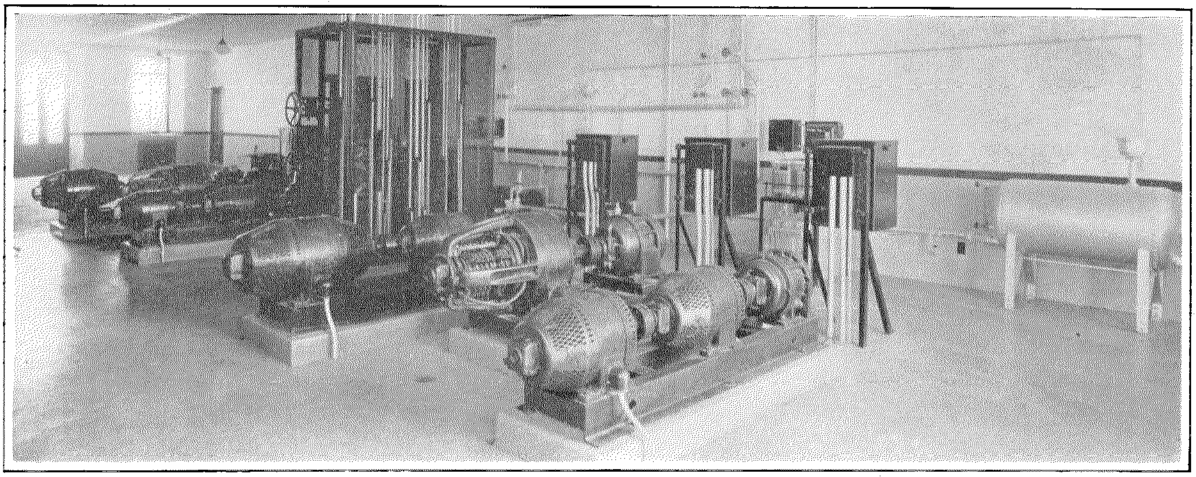
Wave Directive Transmitting and Receiving Antennas," in the February edition of *Electrical Communication.* The frequencies used are approximately 21, 15, and 10 megacycles.

Receiver

The receiver for the New York channel at Buenos Aires is located at Platanos. It is of Western Electric manufacture and is of the superheterodyne type. Two stages of radio frequency amplification are followed by the first detector. An intermediate frequency of 400 kilocycles is employed, the intermediate stage consisting of a band pass filter followed by six stages of amplification, another band pass filter and the second detector. Automatic volume



Receiver at Platanos, Buenos Aires-New York Circuit



Motor Generator Sets at Hurlingham, Buenos Aires-New York Circuit control to minimize the effects of fading is employed. The receiving antennas are of the frame or zigzag type described in the February edition of *Electrical Communication.*

Operators' Quarters—Platanos

Progress in Subscribers' Transmission Apparatus[1]

By L. C. POCOCK, M.Sc., A.M.I.E.E., A.C.G.I.

International Telephone and Telegraph Laboratories, Incorporated

IT is now more than 50 years since the telephone was born to a remarkable career in which it was inevitably destined to become a powerful factor in everyday life. The inevitability of its success lay in its being the most speedy and direct means possible for communication over a distance, and it has, therefore, always been a requirement of telephone engineering that easy, speedy, and comfortable communication should be afforded. To this end, continual development has been necessary and research has yielded an incredible number of inventions which have steadily increased the distance over which communication is possible; today, there is no distance upon the earth that could not be spanned.

New inventions have not only extended the distance over which telephony is possible; some have improved the intelligibility of the received speech, others have permitted an economy in the plant, and every economy in one part of the plant has reacted to make an economy in another more worth while. Thus, it has happened that a certain balance has been maintained, all sections of the plant both large and small being continually forced by study and development to a more economical and higher standard of performance.

The subscriber's telephone set has shared in the general progress that has been made; if it has moved slowly, it is because of the unavoidable inertia associated with the large number in use and the economic difficulties involved in introducing improvements in apparatus which is so widely distributed and sturdily built and which, inherently, has a long life. With these explanations, it may be admitted that the subscribers' equipment is from certain points of view further from the ideal than other parts of the plant, and therefore, capable of the greatest improvement. Improvements are already on the way, and though they must permeate slowly into the established system, progress is both steady and certain.

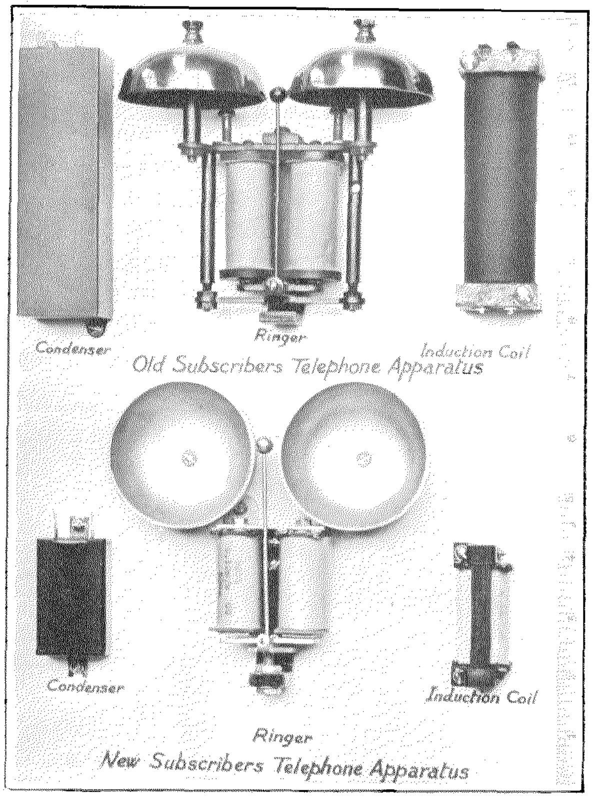

Condenser
Ringer
Induction Coil
Old Subscribers Telephone Apparatus
Condenser
Induction Coil
Ringer
New Subscribers Telephone Apparatus

Figure 1—Subscribers' Old and New Telephone Apparatus.

As of interest in connection with the historical development of subscribers' apparatus, it may be noticed in passing how the tendency towards more comfortable and convenient apparatus has been evidenced by the development of central battery signalling in place of the hand generator, by the employment of a separate bell box with only the minimum of apparatus (transmitter, receiver, and switch hook) on the subscriber's desk, and finally by the development of handsets, or as they are sometimes called, "micro-telephones." With the introduction of handsets comes a return to the more economical arrangement of apparatus in a single unit, the induction coil condenser and ringer which for years have hardly changed in appearance, being now made small enough (Figure 1) to be enclosed in a neat set not occupying appreciably more desk space than the pedestal type of desk stand.

---

[1] Presented before World Engineering Congress, Tokyo, Section 6, October 30, 1929.

The convenience of handsets in preference to fixed transmitter desk sets must have been recognised from very early days, as is witnessed by Figure 2, which is a photograph of what must have been a crude and early model of a handset, probably made up for experimental purposes; the transmitter is an electromagnetic instrument similar to the receiver.

The ordinary fixed transmitter desk stand is commonly placed at arm's length in order to leave the desk top as free as possible for papers and documents. In order to use the telephone the whole instrument weighing 2½ kg. must be lifted across the table before raising the receiver to the ear; this procedure is tiresome and irritating and leads occasionally to the subscriber shouting at the transmitter across the table, a practice which results in extremely bad transmission. Where a handset is installed, a cradle desk stand is naturally and properly placed at arm's length and there is no hardship in picking up the handset weighing about 500 grams and carrying it directly to the ear.

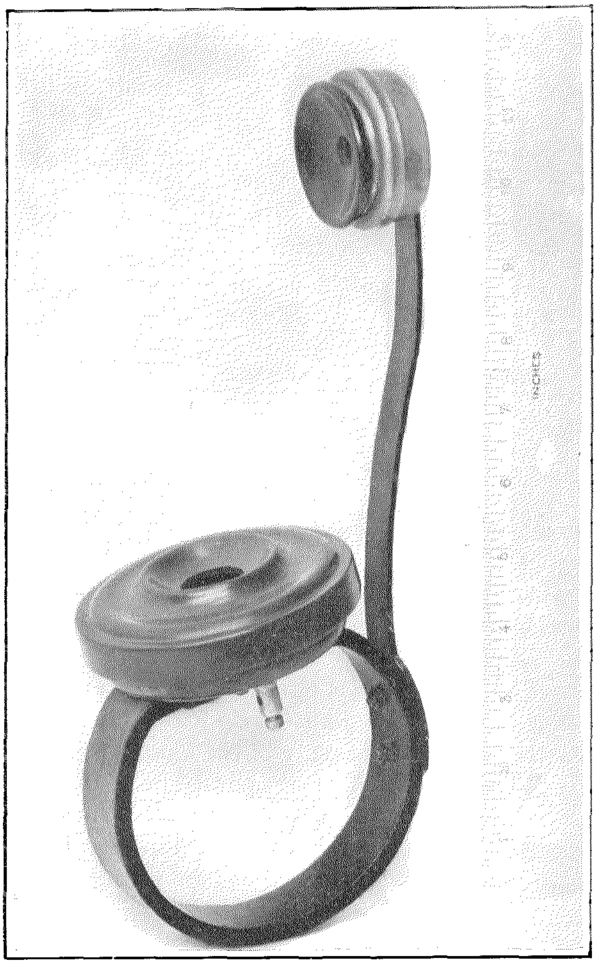


Figure 2—Early Handset Model.

The second and equally important advantage of the handset lies in the freedom of movement which it permits; not only does it allow the speaker to carry on conversation while moving about or searching for papers in the drawers of his desk, but it allows him to lean back in his chair and talk in comfort. Compare this with the severe and erect attitude necessary while talking into a fixed transmitter when business men will often be observed to be in a posture less relaxed even than at other times of working at their desks. It is probably not too much to say that to provide an instrument which enables a busy man to lean back and relax when using the telephone is to do much to ensure that telephone communications shall be treated courteously and sympathetically, resulting in improved understandings and increased business.

The justification on the grounds of comfort for the employment of handsets has been seen to be so overwhelming that a firm demand for them has been established.

Difficulties peculiar to handsets may be classified as:

1. Due to mobility, *i.e.*, the necessity that the transmitter shall operate satisfactorily in any likely position. Under this heading:
   (a) The efficiency should not vary excessively with position.
   (b) The resistance should not vary excessively with position, and in particular, "opening circuit" must not occur.
2. Due to union of the transmitter and receiver on a handle:
   (a) Howling may result from the communication of mechanical vibrations from the receiver to the transmitter.
   (b) The distance between the lips and the mouthpiece is practically fixed by the user's head dimensions; close-up speaking in order to get the maximum effect is, therefore, in general, impossible, and the transmitter must therefore have good efficiency when the speaker is not quite close up to it.

The Practical Ideal Set

As a convenient method of developing the subject of this paper, it is proposed to consider the factors which must be taken into account in aiming at an ideal set, examining the amount of ground that has been covered and the prospect of further improvements.

The specification of the ideal set is not an easy matter, if the conception is restricted to such practical conditions as will make it useful; a single example will show the difficulty. Consider what degree of efficiency is required in the transmitter and receiver and the first conclusion might be that both should be of very much higher efficiency than apparatus now in use. Such a requirement would entail two disasters, one within the subscriber's set and one without. The former would be the excessive side tone requiring a perhaps impossible restriction on the side tone of the set, and the painfully excessive volume received over short lines. The external disaster would lie in the amount of crosstalk likely to occur in the existing plant and this would take the restrictions of the ideal set specification outside the sphere of the subscriber set proper.

It will, therefore, be convenient to dilute the ideal to the extent of considering the subscriber's set that should be built to work with existing telephone plant.

The properties to be considered are listed below. As has been indicated in the example above they are inter-connected so that there is hardly one element that can be varied without in some way affecting one or more other elements.

Transmitter.
- Efficiency of transmitter.
- *Variation of efficiency with position.
- *Microphonicity or variation of efficiency with talking distance.
- Articulation efficiency of transmitter.
- Resistance of transmitter.
- *Variation of resistance with position.
- *Liability to open circuit momentarily when jarred, thus giving false signals at the exchange or interfering with automatic apparatus.
- Life of transmitter.
- Protection of transmitter from moisture (especially in certain climates).
- Burning.
- "Packing" or development of an inefficient state.

Receiver.
- Efficiency of receiver.
- Articulation efficiency of receiver.

Transmitter and Receiver.
- Side Tone.
- Pick-up of room noise.
- *Liability to howl, or to distort as a result of coupling between transmitter and receiver.
- Relation between transmitting and receiving efficiency.

Subscriber Set.
- Frequency characteristic of subscriber's set (i.e., from transmitter terminals to line and vice versa).
- Transmitter, Receiver and Line, terminal impedance.

In the above list those items marked with a star represent features which are peculiar to or which require special attention when the subscriber's apparatus includes a handset.

The ideal set for most purposes in the light of what has been said above, will be taken to comprise a handset mounted for economy on a desk set which contains the circuit apparatus.

In order to elaborate this ideal, certain standards of performance are required, and it will be convenient to refer the performance of any set to the performance of the set in the circuit A shown in Figure 3. This represents a set using a fixed transmitter and ordinary type of telephone receiver connected in a very commonly used circuit. The degrees of comparison with circuit A are expressed in decibels, a unit nearly equal in magnitude to the old mile of standard cable, but independent of frequency.†

In considering the transmitting efficiency of the ideal set, it will be convenient to suppose that the efficiency varies with the current supply as controlled by the loop resistance in a given case in the same way as the efficiency of the transmitter in the Comparison Circuit A. Ideally the less the efficiency varies with current supply the better, but no such absence of variation or even considerable reduction of the variation is possible as long as carbon transmitters are considered. If within these limitations it were possible to augment the transmitter efficiency by any desired amount, how much increase of efficiency would be tolerable. The answer is that for straightforward connection to existing lines with a certain number of short loops no increase of efficiency over the transmitter standard of circuit A is desirable on account of the side tone on short loops and the high speech volume received on short connections. If anti-side tone circuits are adopted the answer is unchanged, but if the shorter loops are furnished with extra resistance to reduce the current supply, the answer is altogether different, since both the side tone and the excessive volume transmitted are simultaneously corrected.

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†When two powers (electrical, acoustical, etc.) are expressed as the ratio P_1/P_2 they are said to differ by N decibels where $N = 10 \log_{10}\frac{P_1}{P_2}$.

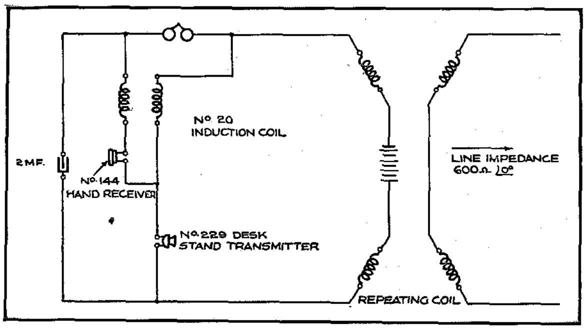

Figure 3—Reference Set—Circuit A.

The controlling factors are that the electrical speech level at the local exchange and the side tone should not be greater than the corresponding quantities in circuit A. If the transmitter in circuit A could be increased in efficiency, the output to the trunk line could be maintained constant by inserting suitable resistance in the local loop. The side tone would then increase slightly because the actual transmitter output would have to increase by the amount of the speech frequency transmission loss in the added resistance, but this would be partly offset by a contrary effect due to the higher impedance into which the set was working, so that the side tone and output to trunk may be regarded as having been simultaneously kept substantially constant by the addition of suitable resistances. The important conclusion to be drawn is that the effect of increased instrument efficiency will be to require the introduction of equalisation in the short loops, rather than to necessitate the use of anti-side tone circuits.

In view of the number of anti-side tone sets recently developed, it will be worth while considering further the arguments for and against an anti-side tone subscriber set.

Side Tone

The question as to whether any side tone is desirable and if so, how much, is one of considerable difficulty. The point involved is principally whether, on account of the higher transmitter efficiency on short loops and the resulting higher side tone, a special anti-side tone set is to be used for *all* stations, since it is generally undesirable to stock two different types of set. Stated in this way the problem is partly an economic one, the (generally) increased cost of the anti-side tone set being balanced against other methods of reducing side tone which can be applied to stations individually in which side tone is objectionable.

Before entering upon the arguments in either direction a few facts in regard to side tone will be considered.

When one is speaking through the ordinary air medium the speech intensity is adjusted automatically according to an estimate of the distance at which the listener is placed. The intensity is further controlled, or perhaps the intended speech intensity is adjusted in accordance with the way in which the speaker hears his own voice. For example, anyone wearing headphones replies in a loud voice when spoken to, while conversation carried on in the presence of noise is conducted in a loud voice with the subconscious intention of maintaining a margin for the speech level above the threshold of hearing for speech in the presence of the noise.

These remarks apply to the artificial hearing of the voice in telephony through the local receiver. The speech intensity adopted in speaking into the telephone is partly controlled by the amount of side tone, and partly by the intensity with which the distant subscriber is received, that is the estimate of distance which the speaker unconsciously forms. It appears, therefore, that side tone properly used may contribute to a desirable adjustment of the speaking intensity.

Experiments on this subject are naturally difficult, involving as they do, observations upon the subconscious adaptions of the persons observed. Experiments have been made, however, and have indicated that the speech intensity adopted is in the average related to the amount of side tone approximately as shown by Figure 4. It will be seen that taking the zero on the side tone scale as about the maximum occurring in practice, a reduction in side tone of about 20 decibels would lead to an average increased speech intensity of 4 decibels. The trend of the curve for greatly increased side tone is uncertain, because some of the persons on whom the observations were made were conscious of the side tone as a noise which they endeavoured to shout down. This was not always the case, however, one speaker, for instance, dropping his voice 12 decibels as the side tone increased from 0 to + 20.

The application of this curve to some typical cases will help in an appreciation of the part played by side tone in practical telephony.

1. *A Local Call between Two Subscribers on Short Loops.*

In this case the transmission is adequate—too loud, in fact. The two subscribers are nearly deafened by each other, with the result that they do not realise how loudly they are talking. In such a case, plenty of side tone exercises a certain amount of restraint and a particularly low side tone might be harmful to transmission.

2. *A Call (Local or Otherwise) between Two Subscribers on Long Loops.*

In such a case either a side tone or anti-side tone set has relatively little side tone, say about −10 decibels on the curve of Figure 4 and an improvement in transmission of 1 to 2 decibels might be expected from slightly louder speaking if anti-side tone sets were used. If the reception is faint, however, this fact will have a stimulating effect upon the speech intensity, probably to a considerably greater extent than 1 or 2 decibels.

3. *A Call (Local or Otherwise) between two Subscribers. One A on a Long Loop and one B on a Short Loop.*

In this case A has a transmitter operating inefficiently and B has a transmitter operating efficiently. The transmission equivalent in the direction A to B is, therefore, greater than in the direction B to A.

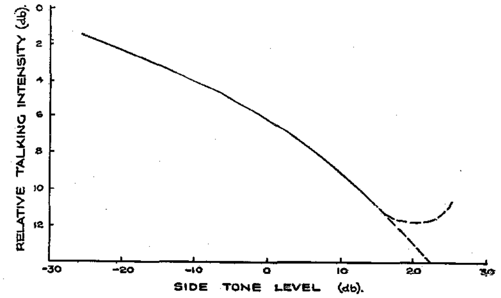

Figure 4—Relation Between Side Tone and Calling Intensity.

According to what has been said B, hearing A more faintly than A hears B, will be inclined to speak more loudly and vice versa, thus increasing the difference in effective transmission equivalents in the two directions. The effect of side tone will evidently be in the direction of restraining this tendency towards inequality of transmission, by causing B to speak more quietly while having relatively little effect upon A.

The feature which sometimes makes side tone objectionable or even painful is not so much the hearing of the natural voice at a rather high level, but the hearing of isolated syllables or vowel sounds at a level far greater than the level of the rest. These take the speaker unawares and are genuinely objectionable. For example, side tone may be scarcely noticeable in such a sentence as:

"When I speak in this way."

while, on account of the transmitter and receiver resonances which are commonly found in the region 800–1,200 p.p.s. accentuating such vowels as "ah," "aw," the same apparatus may be found to have painful side tone when the sentence spoken is,

"Father saw an owl in Oxford."

It follows that improvement made in the frequency response characteristics of transmitters and receivers will tend to make side tone less objectionable. In this connection experiments have indicated that very high side tone is not objectionable when it is high quality speech entirely free from resonant and other distortions.

It may be objected that the room noise picked up by the transmitter and present in the side tone interferes with reception in all cases, that is on any length of loop. This is undoubtedly true, and is the most potent argument that can be brought forward in support of the anti-side tone set, though the interference may, perhaps, be much less when the noise is one to which one is accustomed than when it is an unaccustomed noise such as is usually employed in experiments. The importance of the interference depends upon the amount and character of the noise as much as upon the side tone characteristics of the set.

A long loop generally reduces the transmitter efficiency (by reduction of the current supply) by more than it reduces the received volume of speech, so that for a given amount of room noise the interfering effect will be greater on the shorter loops, and, therefore, any systematic reduction of the efficiency of the shorter loops (equalisation) will ameliorate the receiving conditions in the worst cases. When this has been done, any residual interfering effect due to noise argues in favour of an anti-side tone set, but since all noise is objectionable there is a stronger argument for the reduction or removal of the noise itself. This in the broadest sense is the proper treatment and is a subject now receiving considerable attention in respect to the street noises in big cities.

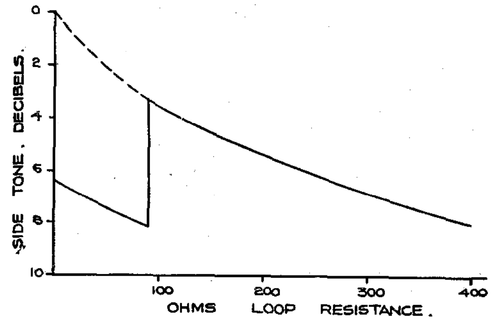

Figure 5—Variation of Side Tone with Loop Resistance.

Summing up the arguments it will be seen that side tone provides a control of the speech intensity which is generally in the right direction, that no increase of side tone is likely to result from future improvements in transmitters and receivers, as greater volume cannot be tolerated on short lines, whereas improvements in transmitter (and receiver) quality will reduce the objectionable character of side tone. A movement towards some degree of equalisation of the transmission equivalent of local lines may be expected in the form of a reduction of transmitting efficiency (and consequently side tone) on the shortest lines; such a movement will be imperative should marked improvement in the efficiency of transmitters be brought about.

A very simple and convenient way of effecting at once both a certain degree of equalisation and a decided reduction in side tone is to alter the connections of circuit A so that the receiver terminal shown connected to the transmitter is transferred to the other side of the transmitter, a change which can easily be made even when the set is installed on a subscriber's premises. If this is done on all loops of less than 90 ohms resistance the side tone (expressed in relation to the side tone of circuit A) will be reduced as shown by the stepped down portion of the curve (Figure 5). At the same time there will be for the short lines a reduction of transmitting efficiency by 3.5 decibels, which tends towards equalisation, and an increase of receiving efficiency of 1 decibel, which tends to discriminate in favour of the received speech against room noise. The side tone reduction connection is seen, therefore, to operate in a very satisfactory manner, reducing the side tone 4½ to 6 decibels, increasing the margin of received speech to side tone noise by 5½ to 7 decibels and reducing by 3½ decibels the transmitting efficiency which is unduly high compared with that of longer loops.

This procedure has been successfully adopted for many years by the American Telephone & Telegraph Company.

The subject of side tone has been discussed rather fully. It is important, and will appear again in succeeding pages, often as a limiting factor and in such a way as to suggest that an anti-side tone set would make everything easy;

but the interlocking of the various elements contributing to the harmonious working of a subscriber's set must not be forgotten. If it has been decided either on technical or economic grounds not to employ anti-side tone sets, then side tone conditions must be carefully watched as one of the factors having a predominating influence. If anti-side tone sets are employed, the element of control over the speaking voice is lost and there may be complaints of excessive reception loudness. In either case any unusual set installed at the moment may be an embarrassment and an obstacle to the adoption later of transmitters and receivers of improved performance, while a standard type of set can by a simple alteration of connections and without extra cost take care of any exceptional conditions calling for reduced side tone.

Microphonicity of Transmitter

This term is used to describe the variation of transmitter efficiency with talking distance. The mouthpiece used determines the pressure on the diaphragm due to sound and generally modifies or distorts the sound by selective treatment of certain frequency ranges. As the talking distance is changed the pressure on the diaphragm may be supposed to vary approximately proportionally to the pressure with which the sound reaches the mouthpiece opening. The transmitter output will not vary according to the pressure on the diaphragm; the microphonic sensitivity of carbon is lower for lower amplitudes, and the loss in output for increasing distance between mouth and mouthpiece is, therefore, greater than would be expected from the reduction in air pressure at the mouthpiece. Comparatively little control can be exercised over the microphonic loss, since a transmitter of a specified resistance and efficiency must have a determined degree of agitation, that is to say, it is working at a given point on the curve relating amplitude of mechanical motion to voltage generated. The reduction in electrical output for any particular reduction of input is therefore determined by the curve which is an approximately constant characteristic of carbon.

Transmitters used in handsets are, like other transmitters, spoken into from various distances, but are unlike fixed transmitters in that this variation is unavoidable. The receiver, because of its small sound output and because the person using it is the judge of its performance is placed on the ear and the transmitter is then automatically located at some distance from the mouth depending upon the shape and size of the user's head. If the handset is made rather small so as to decrease the talking distance in all cases, a certain number of people with rather large heads will not be able to get the mouthpiece opposite their mouth at all and will generally place it right underneath the chin, where it will give very poor transmission. On the other hand, if the handset is made larger there will be a drop in transmission for every user except the small number of out size type, who as a result of the increased length are enabled to bring the transmitter opposite the mouth.

In order to determine the best length to be adopted for a handset the Bell Telephone Laboratories made measurements on the heads of over 4,000 people and plotted them in such a way as to show the position of the mouth in relation to the centre and plane of the ear. The frequency of occurrence of different positions of the mouth is illustrated by the vertical height of the solid model of which a photograph is reproduced (Figure 6). A comparatively small proportion of users represented by the cut away portion will be unable to use the particular handset shown in silhouette with the transmitter properly located to the mouth. The peak of the model representing the most frequently

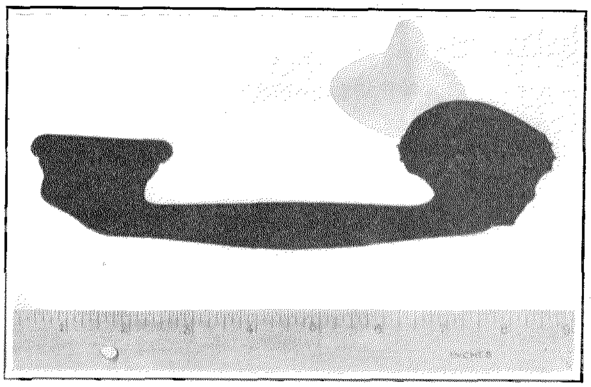

Figure 6—Model for Determining Best Dimensions of Handset.

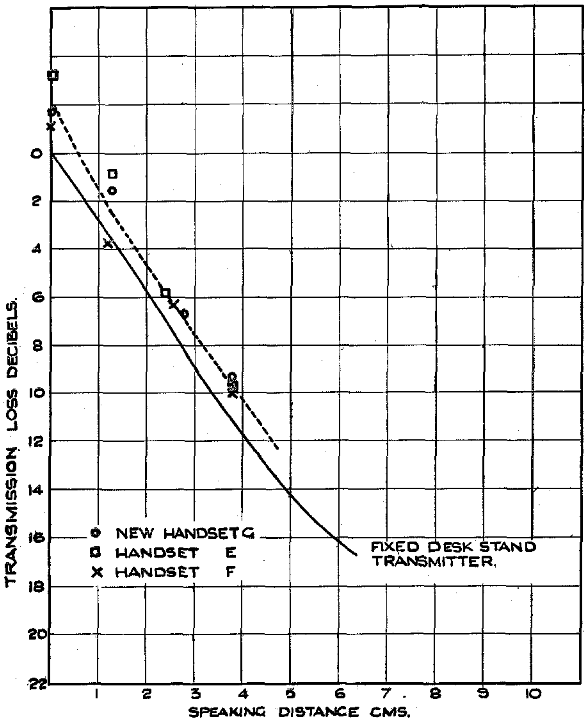

Figure 7—Microphonic Loss Curves for Transmitters.

occurring mouth position is about 1.2 cm. from the centre of the mouthpiece opening.

As an illustration of the kind of variation of efficiency with distance, the results of experiments made on various transmitters are shown in Figure 7, where the full line curve is for a fixed type transmitter. The experimentally obtained values for three different types of handset lie so close together within the limits of experimental error that one curve practically parallel to the curve for the fixed transmitter has been drawn to represent the whole data.

Variation of Efficiency and Resistance with Position

Handsets are liable to be used in a wide range of positions, and it is obviously desirable that the efficiency should change as little as possible with the position of use. In the same way, the transmitter being a resistance operated device must have resistance, but the resistance adopted should vary as little as possible either with position or spontaneously as the result of expansion and contraction of the carbon granules and their containing chamber. Any considerable increase of resistance lowers the receiving efficiency of the set (when the transmitter and receiver are effectively in series), is liable to interfere with the exchange signalling and connecting devices, and may also promote the developing of "burning," that is, the continuous production of transmitter hissing and crackling noises which may make speech reception impossible. Amongst the positions of use of a transmitter must not be forgotten the horizontal position in which it is commonly laid on the cradle or any position in which it may normally be laid down on the table. These positions may be quite different from the speaking position and some difficulty is encountered in designing a handset which shall fulfill the other requirements and yet avoid high resistances in these positions. The importance of avoiding high resistance in the horizontal position is considerable, because at the moment of placing the handset upon the cradle it is submitted to an inductive discharge as the circuit is broken and it is also jarred as it strikes the cradle; both effects promote the development of burning (see Figure 12). A similar consequence follows from the momentary passage of ringing current which may occur as the handset is lifted to answer a call.

The unsatisfactory service given by handsets having bad positional effects was recognised as early as 1907, when American patent 855394 was taken out to cover a transmitter of the solid back type mounted in a handset in the manner shown in Figure 8A. This arrangement is open to certain objections but does reduce the positional effects over that part of the range of speaking positions most used. The next and most notable step was taken by the Bell Laboratories* by inverting the transmitter as shown in Figure 8B. This arrangement is very effective but renders precautions desirable to prevent the ingress of moisture from the breath to the granular carbon and to the paper leaves which are a feature of this transmitter. The arrangement also necessitates rather special weight being given in the design to the factors controlling the face down resistance which, for the construction shown, is evidently liable to be

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*British Patent 263954.

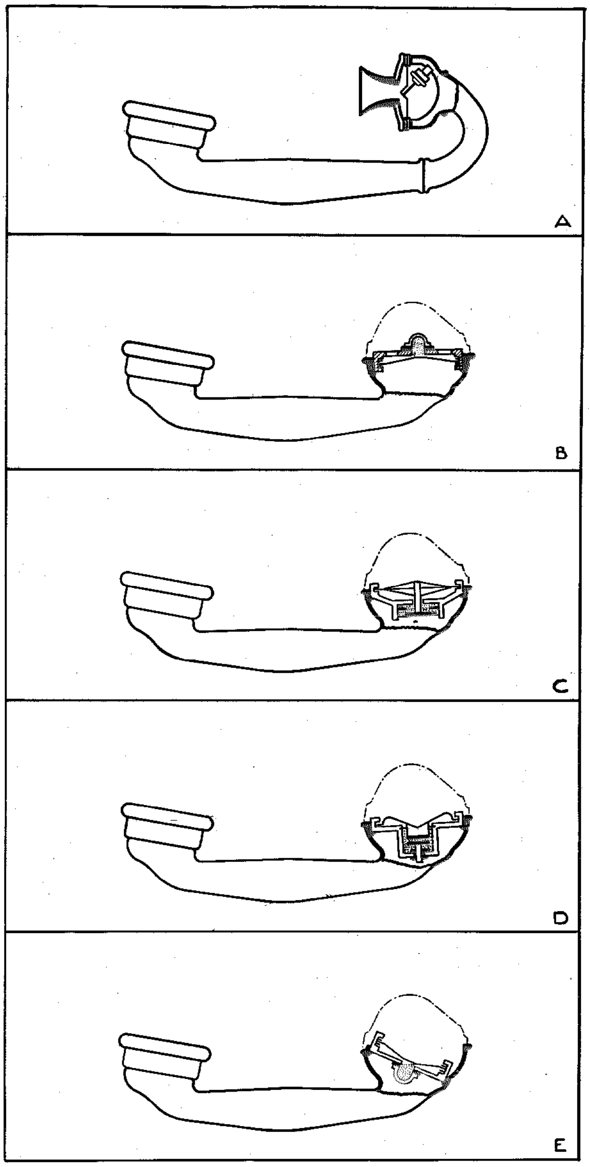

Figure 8—Devices to Secure Good Positional Efficiency in Handsets.

higher than in other positions. Figures 8C and D illustrate two recent British patents** having the same object in view; in case C the transmitter button is inverted and driven by a rod passing through the carbon chamber and in case D a normal type of construction is shown, except that the electrodes are rather deeply immersed in the carbon.

Figure 8E shows the arrangement of a handset to be described in greater detail later.* The transmitter is placed in such a position that its maximum resistance occurs in a position which cannot be adopted while the handset is spoken into, and is unlikely to occur in a position of rest.

The various positional effects which have been referred to are illustrated in Figures 9 and 10, taken from records of development work on different transmitters.

Figure 9, showing the variation of efficiency of handsets with position, exhibits in the case of curve F a minimum value when the plane of the transmitter is vertical. This is quite characteristic of transmitters containing plane parallel electrodes and would seem to be due to mechanical packing of the carbon in the absence of any upward component of the agitating force. (The curves are taken from various sources and may be erroneous as regards their absolute relative positions.)

Figure 10 shows the maximum "breathing"** resistance of several different types of transmitter under a given current condition and for various positions of rest. The resistance values in which the curves terminate on the extreme right are approximately the maximum resistances which occur when the handset is horizontal

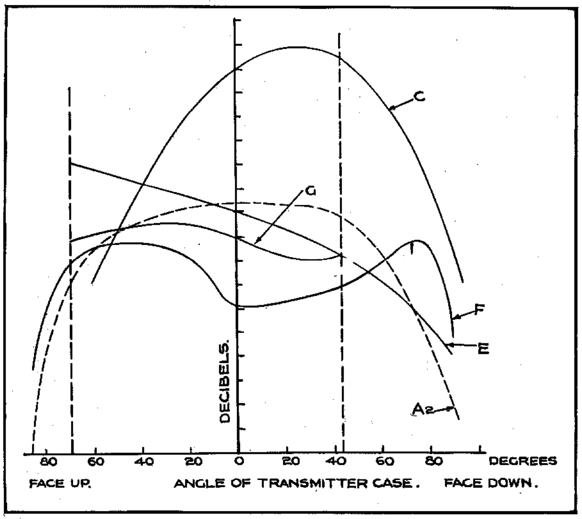

Figure 9—Variation of Transmitter Efficiency with Position.

**Nos. 308630, 308638.

*British Patent 304843.

**This term is used to describe spontaneous changes of resistance in a quiescent transmitter, resulting from the expansion of the carbon and carbon chamber when the current is first switched on or otherwise altered.

as on the table or on its cradle. The region of positions likely to occur while the handset is spoken into in service is between the two vertical lines on the figure, the left-hand part of this region being the most used.

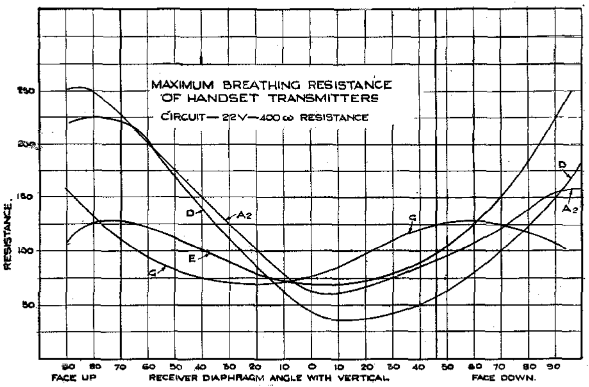

Figure 10—Maximum Breathing Resistance of Handset Transmitters.

In this connection special attention is directed to curve G; it will be noted that the total variation of resistance is the least for this curve and that low resistance has been secured in the important talking position and in the face down position at the expense of a slight increase in resistance for the less normal talking position.

Maximum Momentary Resistance

Another difficulty peculiar to handsets is the more or less violent treatment they may receive, as, for example, when put down roughly on the table when the user wishes to leave the phone during a call. The sudden blow throws the transmitter into violent agitation, causing a momentary high resistance capable in some handsets of causing the supervisory signal to flicker or, in an automatic system, the exchange apparatus to receive a false impulse if such a jar occurs while taking the handset from its cradle or for any other reason before the dialling is completed.

Packing

Carbon transmitters are liable to "pack," that is, to assume a low resistance, inefficient condition which may have its origin in mechanical settling together of the granules or it may be produced by a coherer action resulting from the momentary passage of a high voltage, such as may be produced by an inductive discharge when the circuit is broken. Mechanical packing does not occur in well-designed and well-made transmitters, but electrical packing is readily produced by operation of the switch hook (*e.g.*, to make a second call), while a handset is held in the hand unless special precautions are taken. In some cases the inefficient condition may still persist even though the subscriber speaks fairly loudly into the instrument; it is then necessary to shake or jar the handset in order to re-establish the efficiency.

Electrical packing produced by operation of the switch-hook is interesting as being essentially a radio frequency phenomenon; it can accordingly be reduced or prevented by the arrangement of suitable chokes between the switching point and the transmitter, or by a small condenser shunting the transmitter.

Transmitter, Receiver, and Line Terminal Impedances

The transmitter, receiver, and line terminal impedances of a set are intimately connected with each other and with the induction coil ratio and the receiver impedance.

The impedance at the line terminals of the set should be so chosen that the reflection loss is a minimum for that length and type of line for which a transmission gain is economically of greatest value; *e.g.*, if there are a large proportion of subscribers at such a distance from the exchange that they can just be reached with 24-gauge cable, without reducing the transmitting efficiency below the permitted value, there may be a sufficiently large number of subscribers brought into the 24-gauge cable region by eliminating the reflection loss for this particular kind and length of loop, to justify doing so. Evidently there will be some particular length and gauge of cable for which the concentration of subscribers will be such that the saving in copper effected by a small extension of the zone will be greater than for a similar extension of any other zone. As it is necessary to standardise the set impedance, the varying conditions cannot be met in an ideal manner in different networks, but a reasonable guess at the most probable answer suggests that the set impedance should be conjugate to the line impedance when the line consists of about 3.5 Km. of No. 24-gauge cable.

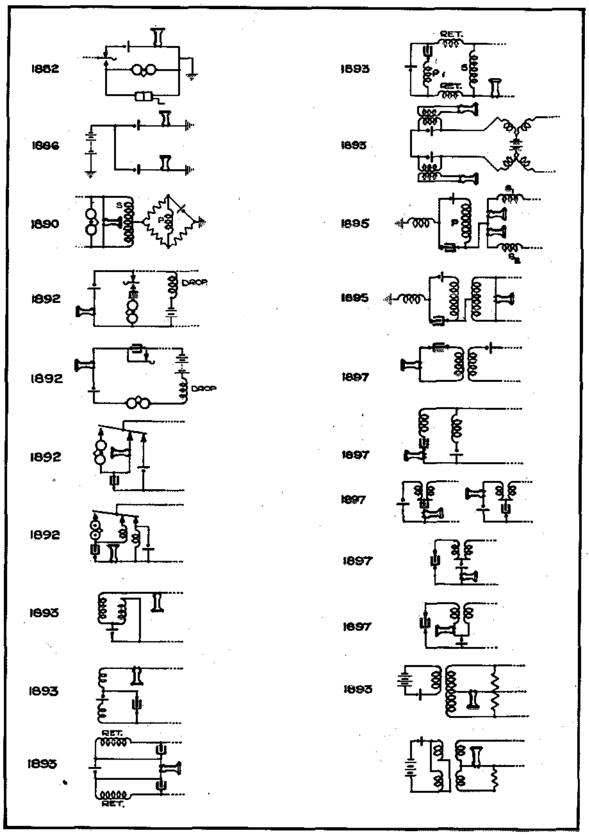

Figure 11—Historical Survey of Subscribers' Set Circuits.

Making suitable assumptions with regard to cord circuit and trunk lines, the desirable set impedance is shown in Table I in comparison with the measured impedance of various sets.

The figures given in the table illustrate the kind of difficulties encountered as a result of mutual reactions between diverse requirements. Set (a) is comparatively low in terminal impedance compared with the ideal value at 800 p.p.s. Set (b) gives a better match and has better receiving efficiency, but it also has 4-5 decibels more side tone. Sets (c), (d), and (e) have a lower impedance receiver in order to restore the receiving efficiency and side tone to more normal levels, a result which is accomplished at the expense of a disadvantageous change in the phase angle of the set impedance. On the whole it is not possible to give much weight to the set impedance, other more important factors controlling the situation.

Quite a large number of subscribers' set circuits have been proposed. The subject is too large to discuss fully in this paper, and even with a single type of circuit different combinations of induction coil and receiver windings give a great variety of results.

Factors which have had an influence on the evolution of subscribers' circuits are cost, efficiency, frequency characteristic, freedom from painful clicks in the receiver when the switchhook is operated, side tone, and adaptability to the fitting of a dial for automatic work. This last requires that the operation of the dial shall not produce clicks or excessively high voltage discharges resulting from breaking inductive circuits.

Various circuits that have been developed are shown in Figure 11. The last of the 1897 sets has found the most widespread use and appears to meet all the requirements in a satisfactory manner. Its line terminal impedance when fitted with the usual fixed transmitter and hand receiver is given under (a) in the table.

Relation between Transmitting and Receiving Efficiency

The subscriber's set being a six-terminal network joining line, receiver and transmitter, it is possible by choice of the induction coil ratio and the apparatus impedances to increase the transmitting efficiency within certain limits at the expense of the receiving efficiency. It may be accepted as the result of experience and evolution that the relation between the transmitting and receiving efficiencies of the set shown in the circuit A, Figure 3, is adjusted to the best all-round compromise. It must be remembered, of course, that the transmitter output depends upon the battery supply current and, therefore, the performance is not fixed as in the case of the receiver. There is an advantage in keeping the transmitting efficiency high in relation to the receiving efficiency, as any increase of the latter intensifies the line noise as well as the speech, and consequently improvements in receiver efficiency lose most of their value and are preferably sacrificed (by reducing the impedance of the receiver or by altering the ratio of the induction coil) to give an increase in transmitting efficiency. The transmitting gain obtainable is, however, not at all great and is liable to be accompanied, when secured by alteration of induction coil ratio, by a disproportionate increase in side tone, and when secured by reduction of receiver impedance there are difficulties in maintaining the desired shape of the transmitting and receiving characteristics of the set.

Howling

The fact that the ordinary carbon microphone is a non-reversible mechanism possessing a considerable degree of energy amplification makes it possible under certain conditions for any disturbance in the receiver to excite the transmitter in sufficient degree to feed back energy as side tone to the receiver, and so set up a sustained howl, depending for its pitch upon the mechanical and electrical constants of the system. The mechanical coupling between the transmitter and receiver of a handset is partly through the open air, but with efficiencies at their present level the coupling is not sufficient to cause howling, and it is not likely that the efficiencies (unless it be at single resonant frequencies) will ever reach such a value that this becomes a serious consideration. The coupling between transmitter and receiver through the handle is, however, a more serious matter. It has been found that in order to prevent howling there should be no parts of the handle mechanical transmission system resonating in the range of frequencies for which the transmitter or receiver is liable to resonate. Such mechanically selective systems may occur wherever surfaces are joined, on account of the uneven and uncertain pressure between them and the reflections which arise at the discontinuities. The best way of avoiding these effects is to avoid a complex system by using as few parts as possible, mounted on a handle of material possessing such high stiffness that the necessary weights of the transmitter and receiver do not resonate with the handle as a whole, and finally any joints that are necessary should be as positive as possible.*

Any tendency to howl, even though actual howling never occurs, must cause distortion in the transmitted speech as the result of the damping coefficient being low, and the response relatively high in some regions of frequency. It is, therefore, desirable that there should be a considerable margin of safety. According to repeater practice the margin might be 7 decibels, that is, an amplifier inserted between the transmitter and receiver should not cause howling until the gain increases the side tone by 7 decibels at least. It is better, of course, to increase this margin if possible.

In illustration of the value of the moulded bakelite construction in reducing the liability of a handset to howl, figures are given below for the principal resonances of various handsets. There may be other resonances, but the principal ones are usually respectively due to the transmitter and receiver moving parts and to the elasticity of the handle loaded with the weights of the transmitter and receiver.

	Transmitter Resonance	Receiver Resonance	Handle Resonance
Moulded handset A	1140 p.p.s.	900 p.p.s.	2300 p.p.s.
Moulded handset B	1300-1400 p.p.s.	1050 p.p.s.	2200 p.p.s.
Moulded handset C	1700-1800 p.p.s.	800 p.p.s.	2200 p.p.s.
Ordinary handset built up with ebonite and brass	1050 p.p.s.	850 p.p.s.	970 p.p.s.

It is at once apparent that the three moulded handsets which differ widely in construction, all have a handle resonance fairly remote from the transmitter and receiver resonances, while the older type of built-up handset has three closely similar resonances, and has in fact a considerably greater tendency to howl.

Burning, Moisture Proofing and Life

A determining factor in the microphonic life of a transmitter is often what is known as "burning"—that is, the phenomenon of discharges in the transmitter causing crackling and hissing noises in the receiver. Burning is provoked by high resistance in the transmitter, and since increase of resistance generally occurs during life, burning is always liable to appear in service, though absent when the transmitters are new.

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*British Patents 175495, 211141, 239693.

It may be stated in a very general way that burning prevention places one of the severest limits upon the efficiency of a transmitter built according to any given principle. Such alterations of dimensions as would increase the efficiency are nearly always such as to increase the danger of burning developing when the carbon has aged to the maximum amount. Many factors contribute to intensify the increase in resistance, which in its turn brings increase of burning, the most potent being mechanical agitation, ingress of moisture, and the passage of more or less momentary high voltage discharges, such as the inductive discharge occurring when the switch-hook is operated, or the momentary passage of ringing current when answering a call. To mitigate the results of these discharges the transmitter should preferably have a low resistance in the hanging up position in order that the actual voltage across its terminals may be reduced as much as possible.

In illustration of the ageing effects occurring in a handset transmitter, Figure 12 has been prepared showing the results obtained with a handset having parallel electrodes. The abscissae, except in the case of (c) below, represent the number of operations consisting in dropping the handset horizontally from a height of 5 cm. onto its cradle. This is naturally a severe test and exaggerates somewhat the mechanical ageing of the carbon. Three variations were adopted: (a) handsets dropped as described and connected in the electrical circuit associated with the cradle switch; (b) handsets similarly dropped but not carrying current; (c) handsets carrying current and connected to a periodically operated cradle switch but not subjected to any mechanical disturbance.

The results show very clearly how both the mechanical disturbance and electrical discharges contribute to an increase of resistance, and they also bring out the interesting result that the increase of resistance tends towards a limit.

Moisture proofing of transmitters would materially help their operation in highly humid localities. The difficulty lies in the strained condition set up in a closed elastic structure, such as a button, by the difference of pressure inside and outside, caused by the expansion of the closed air when warmed by the evolution of heat in the granular carbon or by variation of the atmospheric pressure. In a recently developed transmitter, which will be more fully described later, protection is effected by a membrane which, if sealed, can take up the alteration in volume and pressure without causing a difference of pressure to operate upon the transmitter element.

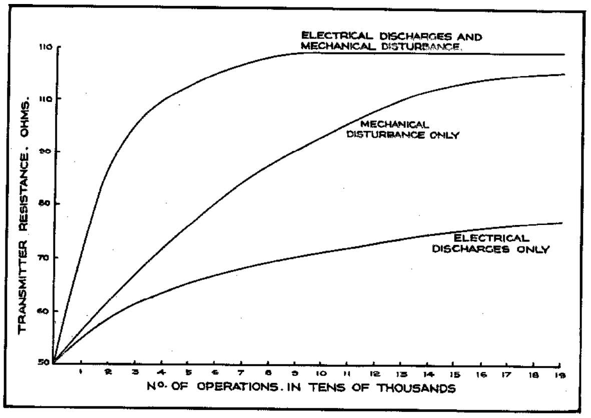

Figure 12—Variation of Transmitter Resistance During Life Test.

Development of a Set

In the foregoing pages the requirements and properties desired in a modern subscriber's set have been dealt with in general and some examples have been given to show the kind of data that has to be secured. For convenience in handling the subject, the various requirements have been separated and dealt with singly. It will be realised, however, that a certain amount of compromise is necessary, and that the proper adjustment of the various factors is, on account of the interlocking of the data, a long and laborious piece of work. For example, a transmitter may be developed to the point where nearly all the required data has been obtained, when life tests, which are slow and necessarily give delayed results, may show up defects which necessitate some small change in the design, and the whole series of tests has to be reconducted, There is thus no very well defined logical order of development and testing.

Finally, when an instrument has passed all the laboratory tests satisfactorily, there are still trials and difficulties ahead. Manufacture on a large scale will present new problems and bring to light the effect upon performance of ordinary manufacturing variations in dimensions or materials. Launched in service the apparatus will have to stand undefined ill-treatment and extremes of temperature and humidity. These may show up defects not revealed by the more regularly controlled laboratory trials. Without entering into extensive details, it may be mentioned that difficulties encountered during manufacture and service have included use of materials of unsuitable temper flowing and settling under stress with loss of efficiency, evolution of products harmful to the carbon under the influence of heat developed in the button, burning arising from carbon granules becoming wedged in joints of the structure, loss of magnetism in the receiver, undesirable movements of the receiver diaphragm resulting from temperature changes, sticking of the switch-hook, corrosion or damage to finish with numerous other troubles arising from vibration or loosening of parts as a result of atmospheric variations.

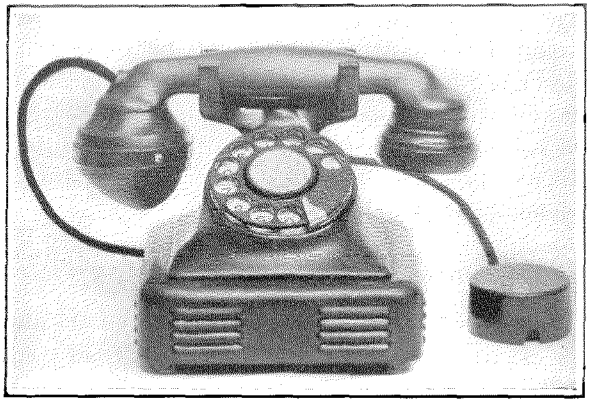

Figure 13—Modern Telephone Subscriber's Set.

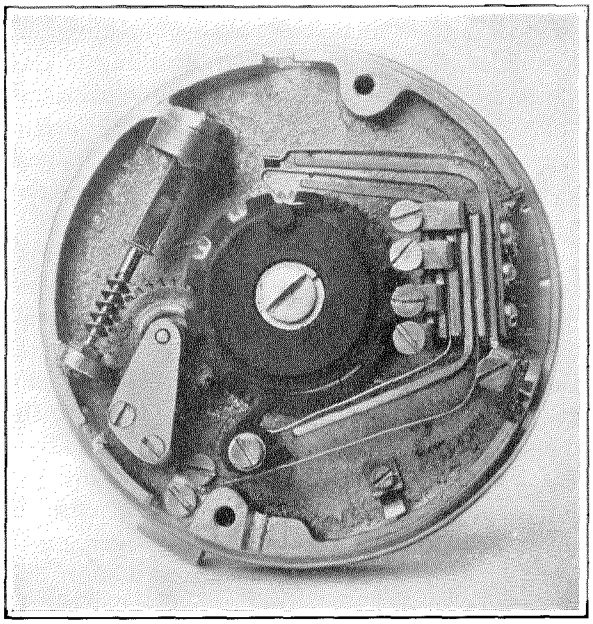

Figure 14—Dial.

Description of a Modern Set

It now only remains to describe in some detail a modern telephone subscriber's set recently developed in the laboratories of the International Telephone and Telegraph Corporation.

The set is illustrated in Figure 13. It consists of a pressed iron base or apparatus box which ordinarily mounts the ringer, condenser, and induction coil, while a cast metal upper part provides a rest for the handset and mounts the switch-hook and dial. The upper part can be mounted upon different apparatus boxes when special sets are required (intermediate-through sets, or sets with separate ringer, etc.).

Miniature apparatus as illustrated in Figure 1 permits the dimensions to be reasonably small. Attention is specially directed to the transformer type induction coil in which a laminated core, furnished with suitable air-gaps to prevent saturation, is provided.

The dial is of new design (Figure 14) specially suitable for mounting any desired spring combination, and provided with means of accurately adjusting the steel clock spring after assembly. Care has been taken to provide adequate sized finger holes while retaining the necessary margin of idle rotation of the dial to allow the exchange apparatus to operate fully before another digit is dialled.

The handset contains several new features which have been developed as a result of studying the complex requirements which have been discussed. The most casual examination of the interior arrangement (Figure 15) will reveal that the transmitter is mounted in a position never before adopted.* Earlier handsets have been either straight, with the plane of the transmitter diaphragm parallel to the receiver diaphragm plane or, by curvature of the handle or tilting of the transmitter, the transmitter diaphragm has been made to face slightly towards the mouth. In the handset now described, the transmitter has been tilted in the opposite direction, that is to say, away from the mouth. One of the reasons for this arrangement is illustrated in Figure 16, where it will be noticed that in ordinary use a handset is not held with the handle vertical but inclined backwards; the forward tilt of the transmitter brings it more nearly into the slightly inclined position in which a fixed transmitter is used. Similarly, in a more extreme position, with the handle lying back almost horizontal, the transmitter cannot be so placed that the carbon falls away from the diaphragm and so ceases to be driven. A handset may be used in a variety of positions of which the limits are approximately with the receiver diaphragm 70° to the vertical and face upward to a position in which the receiver diaphragm is 45° to the vertical and face downward, and it is important to avoid wide variations of efficiency over this range of positions. The forward tilt of the transmitter is designed to avoid the otherwise inevitably large variation of efficiency by making the position of use of the transmitter diaphragm vary round the vertical. The position in which the transmitter has lowest efficiency is, of course, that in which the carbon falls away from the diaphragm and so fails to be effectively driven; it is impossible with the forward tilted transmitter to speak into the handset with the transmitter in this position.

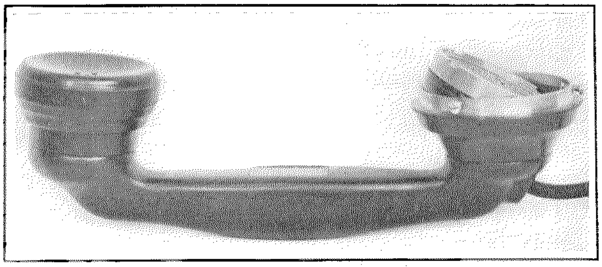

Figure 15—Interior Arrangement of Transmitter in Handset.

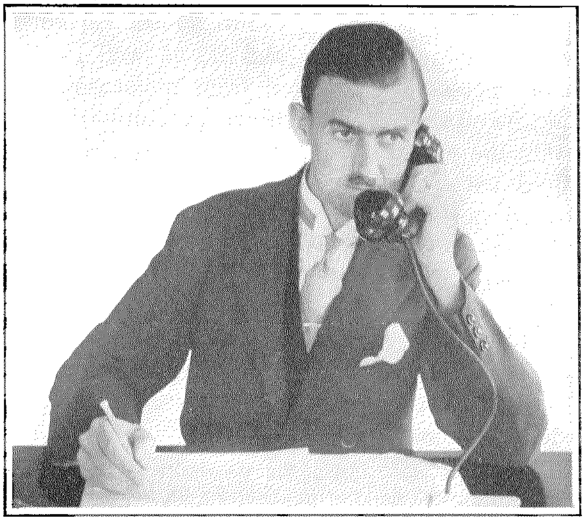

Figure 16—Handset in Ordinary Use.

The transmitter button is very similar to that shown at B in Figure 8. It has already been pointed out that an inverted transmitter such as this may have a rather high resistance in the face down position, besides being exposed to moisture. The inclined arrangement of the transmitter enables freedom from excessive effects in the talking position to be secured without introducing a high resistance in the face down position and at the same time better protection from moisture is secured.

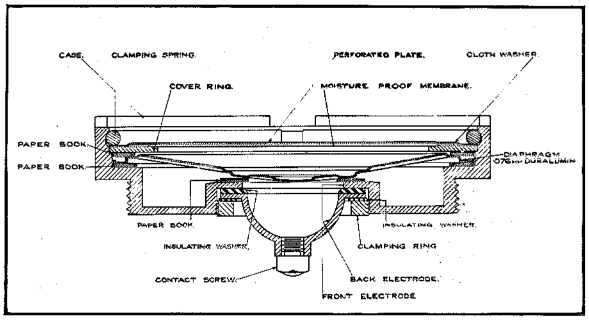

Figure 17—Transmitter Button.

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* British Patent 304843

As may be seen from Figure 17 the carbon is behind the diaphragm and it, as well as the paper books, is protected from moisture by a thin membrane of specially treated material.

On the whole it has been considered that the tilted transmitter position was inherently the logical position in which to mount the transmitter and that it disposed at once of practically all the operational difficulties of a handset.

This new departure in the arrangement of a handset transmitter is at once so fundamental in its effect and so novel in itself that it seems desirable to recapitulate briefly the advantages which it secures; these are:

1. Reduced effect upon the transmitter efficiency of using the handset in various more or less extreme but usual positions.
2. Reduced variation of resistance with position throughout the range of normal use.
3. Avoidance of opening circuit momentarily when jarred in the face down position.
4. The transmitter is not in its maximum resistance position in any speaking position or when held horizontally face down, in which position it may be subjected to the destructive effects of ringing current, inductive discharge from switch-hook operation, as well as mechanical jolts.

While points 1 and 2 may be secured by the reversed button position which has already been referred to, points 3 and 4 will in general not be covered by such an arrangement.

Passing now to a consideration of the transmitter construction, it will be seen that the diaphragm is a light rigid duralumin cone without any attachment so that the moving part has an absolutely minimum weight of the order of 0.5 gram. The diaphragm is elastically supported between piles of paper rings which represent mechanically the equivalent of a condenser shunted by a resistance both in series with the inductance representing the mass of the diaphragm. This construction has the advantage of providing a stiffness which will tune with the diaphragm to a damped resonance at a fairly high frequency without making the system so stiff as to restrict the output at the lower frequencies.

The operation of the transmitter avoids the use of any moving electrode, the moving diaphragm serving merely to vary the pressure upon the carbon and so vary the resistance between the fixed electrodes. It is this circumstance that makes possible a light moving system with mechanical restraints which are designed to fulfill the mechanical requirements only, without being complicated by the necessity of conducting battery current between the capsule case and the diaphragm.

The mouthpiece is the result of much experimental work, in the course of which it was appreciated that the transmitter considered alone had such high quality characteristics that the influence of any acoustic resonance in the mouthpiece would be relatively great, *i.e.*, more distinctly appreciable than in transmitters with heavier parts possessing strong resonances of their own. It was, therefore, necessary to adjust the mouthpiece resonance very carefully in order that it might contribute adequately to volume efficiency and cause the minimum loss in articulation.

The receiver is of new construction containing a short cobalt steel magnet with welded on pole pieces. The short magnetic path enables exceptionally high efficiency to be obtained, while the high coercive force of the magnet material enables an exceptionally short magnet to be used without fear of demagnetisation occurring. The coils are wound on formed spools which may be readily replaced should any such repair become necessary.

The earcap has been carefully designed to give a good acoustical performance. It is well known that receivers practically always resonate strongly at about 800–900 p.p.s. or in practice, when placed on the ear, they resonate at about 1,100 p.p.s. This comparatively sharp resonance has been substantially reduced by dividing the air space in front of the diaphragm into two parts with a narrow connecting channel. The effect has been to increase the damping coefficient (in open air) from 100 to 250 and a gain of about 4% in articulation has been secured.*

The handset, as a whole, has received considerable attention from the point of view of securing a good appearance, although it has naturally been felt that good electrical performance was the first essential. Two points only regarding the general design need to be mentioned. First, the rigid coupling together of all parts in such a way as to prevent any part of the structure resonating at a low frequency and so producing howling,* a feature of the design which is important from the point of view of mass production because while a few samples of any type may be free from howling or may be made free from howling by adjustment of the screws securing the separate parts, a certain proportion of the mass product will inevitably howl unless the design inherently ensures that all parts are rigidly and uniformly clamped together.

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*Articulation is measured by the proportion of meaningless syllables correctly written down by observers to whom they are transmitted over the various systems or apparatus to be compared.

The second point to be mentioned is the mouthpiece, which has been made in the so-called hygienic form, that is to say, the external surface is smooth and readily wiped. There is much that can be said about hygienic mouthpieces and opinions are very much divided, but this is chiefly due to the name which is something of an exaggeration. All mouthpieces contain openings leading to inaccessible parts, and it is always possible, if rather unlikely, that dangerous germs will be harboured in these parts. The most real danger of a mouthpiece is that of contact with the lips, a contact which in the case of a public telephone is naturally repulsive. The new mouthpiece has been designed so that the centre of the grid is nearer to the face than other adjacent parts and at such a distance that very nearly everyone can use it without danger of contact. At the same time, it can be quite easily wiped and kept clean. It is this feature of cleanliness to the eye and the avoidance of a repulsive appearance which is a justification for the use of a closed mouthpiece.

Performance

The performance of the handset that has been described cannot be adequately stated without a clear idea of the relative values for telephone transmission of loudness and freedom from distortion. The best criterion is evidently the ability to convey intelligible speech under unfavourable conditions, such as, for example, to afford communication over a long line in the presence of a certain amount of line noise. It is evident that the speech must be received with sufficient loudness to be heard above the noise, and it is also evident that the less distortion there is the more satisfactory will be the communication.

There is quite a difficulty in evaluating the two elements separately. Any new apparatus must naturally be compared with known existing standard apparatus and if the new apparatus distorts less than the old the comparison of volume efficiency is difficult and almost arbitrary. The apparatus having the greater distortion producing a good deal of noise on certain resonant vowels, it is an open question whether the better quality apparatus should be compared in loudness with the loudest sounds of the standard apparatus or with the more articulate sounds produced by less resonant sounds. Probably a fair estimate of the loudness comparison would be intermediate between these two, but this calls upon the ear to perform an integrating and averaging process which may, perhaps, be attempted in a voice-ear comparison, but which necessarily produces rather uncertain results.

Bearing these facts in mind it is believed that the volume efficiency of the new transmitter speaking an average distance from the mouthpiece may be fairly assessed at 2 decibels below that of the transmitter in circuit A when speaking close to the mouthpiece or, taking into consideration service conditions in which the fixed transmitter is spoken into from a distance of about 1.8 cm. on the average, the handset transmitter is about 3 decibels better than the fixed transmitter.

The new transmitter is relatively free from distortion compared with earlier types; suitably mounted with an open front it can in fact be used as a high quality microphone for announcing work.

A number of articulation tests have been made between two subscriber sets similar to circuit A but fitted with handsets in comparison with the same two sets containing the transmitter and receiver of circuit A. Ten observers were used for these comparisons. The following results were obtained:

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*British Patent No. 211141.

Apparatus	Per cent. accurately recorded of syllables called.
Circuit A, fixed transmitter and hand receiver	66.5%
New handset	81.7%
Articulation gain with handset	15.2%

This gain in articulation represents a considerable improvement in service capability and is worth several decibels in loudness.

Other data upon the new handset has been given in this paper though it is not possible at the moment to give the complete data that is being obtained, some of it not yet being sufficiently firmly established for publication.

The following is a summary of the data available:

Transmitter

Articulation.	11% better than the transmitter standard in circuit A.
Efficiency.	2 decibels below the transmitter standard in circuit A.
Microphonic Loss.	Figure 7.
Maximum breathing resistance in any position.	Figure 10 Curve G.
Variation of Efficiency with position. (provisional data)	Figure 9 Curve G.
Burning.	Negligible.
Howling.	None.
Breaking Circuit and releasing exchange apparatus.	None, up to 1,000 ohm line.

Receiver

Articulation.	4% better than the receiver standard in circuit A.
Efficiency	Equal to the receiver standard in circuit A.

TABLE 1.

Impedances of Subscriber Sets.

Conjugate of line terminal impedance for 3.5 km. of 24-gauge cable.	800 pps.	1,500 pps.
	600+j600	440+j440
(a) Sub. Set Figure 3	285+j218	303+j342
(b) Sub. Set as Figure 3 but higher ratio coil	520+j300	470+j465
(c) Sub. Set on Figure 3 but lower impedance receiver & 55ω transmitter.	438− j82	385+j167
(d) Sub. Set as (c) but higher ratio coil	474− j21	389+j193
(e) Sub. Set as (b) but lower impedance receiver	660− j15	445+j304

A System of Electrical Transmission of Pictures[1]

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Introduction

AMONG the many ancient and revered customs which still survive in present-day Japan, even though the origin of some of these be lost in the mists of antiquity, none is of such transcending importance, or of such vital interest to the people, as the series of impressive ceremonies lasting nearly a month, which mark the accession of a new Emperor to the Throne.

Such an event took place in November, 1928, when the present Emperor ascended the ancient throne of Japan and inaugurated the era of "Showa," or "Enlightened Peace." For the first time in history, photographs of the stirring, colorful scenes and stately processions incident to the event, and so dear to the hearts of all Japanese, were flashed from one city to another by wire, and reproduced day by day in the leading newspapers of the Empire.

The approach of the Coronation period stimulated the efforts towards a practical use of the picture transmission art to such an extent that by November, 1928, the service was fully established between Kyoto, the ancient capital, where most of the ceremonies took place, and Tokyo, the present capital; also between Tokyo and Osaka, the terminals being located in the offices of the principal newspapers in the cities mentioned.

Previous to this period, or about 1924, some tests had been made, using the early Belin and Korn systems, but these were experimental only, were not particularly successful and did not reach the practical stage. However, in July of 1928 the Department of Communications issued amended regulations permitting the electrical transmission of pictures by newspapers or news agencies having private or leased communication lines, and the commercial age of picture transmission in Japan may be said to date from this period.

The transmission system which is described in the following has been developed by the writer with the assistance of Mr. M. Kobayashi, his colleague in the Nippon Electric Company, Limited, and, therefore, is named the N. E. system. This system has been installed in the Tokyo Nichinichi Shimbun (Tokyo Daily News) and the Osaka Mainichi Shimbun (Osaka Daily News) since the beginning of picture transmission in this country and has been giving very good results in the service between Tokyo and Osaka.

The Coronation resulted in a record-breaking traffic in the transmission of pictures. During twenty-two days, which intervened between the Emperor's departure for Kyoto and his return to Tokyo, the number of pictures transmitted by the writer's system amounted to two hundred and fifty-three, of which one hundred and fifty pictures appeared in the newspapers. In point of time of transmission and reliability, exceptionally satisfactory results were obtained. For instance, on November 6, the pictures of the Imperial Procession and Imperial Carriage, which were photographed by the Picture Squad of the Coronation on the Double Bridge in Tokyo at 7:10 a.m., as the Emperor left the Palace for the station, were received in Osaka at 8 o'clock, less than an hour later, just as the Imperial Train was pulling out of Tokyo Station. These pictures, together with other events of the day, were published in Osaka on a four-page extra, first by the Osaka Mainichi at 9:30 in the morning. This, we believe, sets a record, which should adorn the first page of the history of picture transmission in Japan.

Generation of Picture Current

In the present system of picture transmission as in most of the other systems in use today, the picture to be transmitted and the receiving film are wrapped, respectively, around drums which are synchronously rotated and at the same time driven in the direction of their respective axes. At the transmitting end, of which a brief schematic sketch is shown in Figure 1, a toothed rotating disc is used to interrupt the light emanating from a source. A pulsating light flux thus produced is projected upon the picture or the picture film.

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[1] Presented before World Engineering Congress, Tokyo, Section 6, October 31, 1929.

If the cross sectional shape of a light flux emanating from a source is properly selected by adapting the shape of the screen-opening through which the flux passes, a pulsating light flux represented by equation,

$$\phi = A + A \sin \omega t \ldots\ldots\ldots\ldots\ldots (1)$$

may be projected upon a picture to be transmitted by alternately interrupting the above light flux with the teeth of a rotating toothed wheel. As regards light the transmission ratio of a picture film or the reflection ratio of a picture varies with the color-tone of the picture. If this variation with respect to time is represented by function $F(t)$, then the light transmitted through a film or reflected from a picture is expressed by

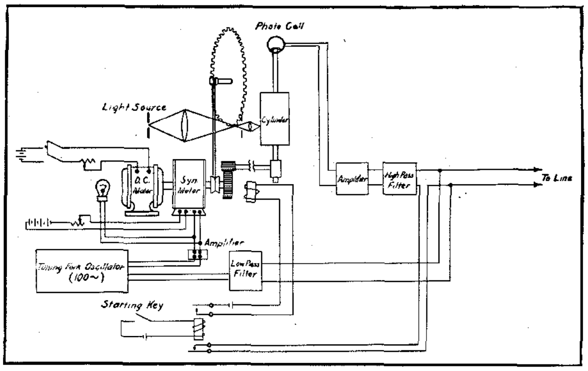

Figure 1—Sending System (Aerial).

$$\begin{aligned}\phi &= F(t)\, A + A \sin \omega t \\ &= AF(t) + AF(t) \sin \omega t \ldots\ldots\ldots (2)\end{aligned}$$

This light acts upon the photo-electric cell.

Figure 2 shows the construction of the optical system at the sending end. The light transmitted through the film is led to the photo-electric cell by the prism, while the light reflected from the picture reaches the cell through the combination of the paraboloidal and the cylindrical mirrors. The focus of the paraboloidal mirror coincides with the light spot on the picture to be sent so that the light will directly be gathered into the cell after the reflection. The cylindrical mirrors will also lead the light into the photo-electric cell after successive reflections. Assuming that the electric current from the photo-cell varies with the intensity of light, this current may be expressed by

$$I = AKF(t) + AKF(t) \sin \omega t \ldots\ldots (3)$$

where K is a constant. An examination of (3) shows that $AKF(t)$ is a current generated in the photo-cell by a constant light flux A being modulated in accordance with the color-tone of the picture. It is also seen that $AKF(t) \times \sin \omega t$ is a current produced by an alternating current $AK \sin \omega t$ being modulated in accordance with the color-tone of the picture. It is thus seen that from the photo-cell flows a current corresponding to the color-tone of the picture superposed by a carrier-current modulated in accordance with the color-tone of the picture. For the purpose of picture transmission either current may be used, but from considerations of transmission characteristics and the efficiency of amplification, it is better to use the carrier-current, and hence a pulsating flux is used. In order to separate these two currents a wave filter is employed and the carrier-current $AKF(t) \sin \omega t$ is taken out. If no wave filter is used and the two component currents are transmitted together, the quality of the picture received is affected greatly by blurs due to the difference in the transmission characteristics, such as the amplification ratios

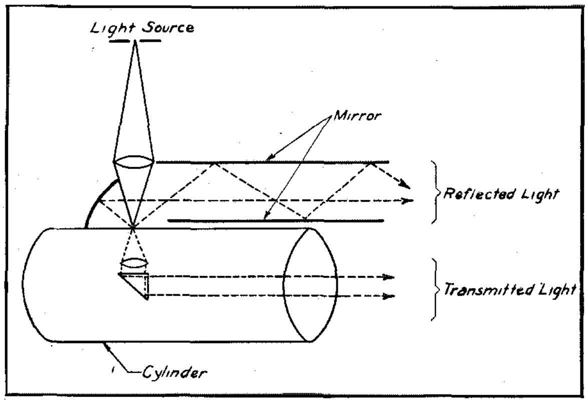

Figure 2

of the amplifier and the speeds of propagation of the two currents. Figure 6 is a picture received without the use of a filter and Figure 7 is one received when a modulated carrier-current only was transmitted by employing a filter; the difference in results being easily seen.

Synchronization

The methods for synchronous operation used in the transmission of pictures may be divided roughly into two kinds. In one, synchronizing current is used, while in the other a source of alternating current is provided separately for the sending and receiving stations, respectively, where synchronous operation is performed by carefully regulating the frequency of the alternating current. In the present system the former method has been adopted.

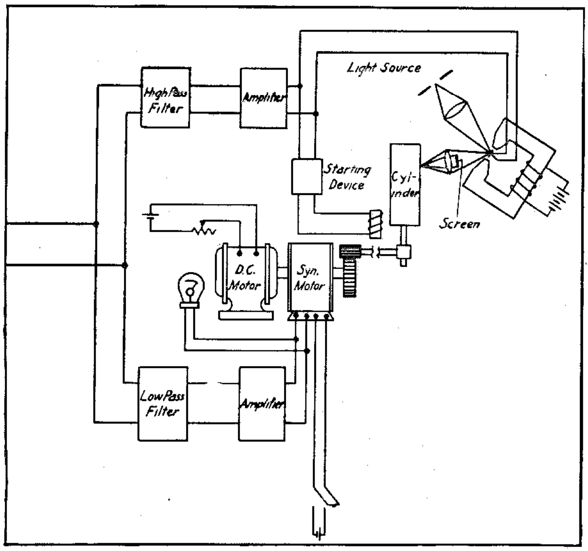

Figure 3—Receiving System (Aerial).

For the equipment to be used in connection with open wire lines an alternating synchronizing current of 100 cycles per second is generated at the transmitting terminal by a tuning fork oscillator to drive thereby the synchronous motor at this station, and at the same time this current is transmitted over the line superposed upon the picture carrier-current to the receiving terminal where, after being amplified, it is supplied to the synchronous motor. In the case of equipment to be used in connection with a telephone cable comprising telephone repeaters, transmission efficiency is low for an alternating current of 100 cycles per second. For this reason alternating currents of 350 and 450 cycles per second are generated at the transmitting terminal and these currents are transmitted superposed upon the picture carrier-current as shown in Figures 4 and 5. At both the transmitting and receiving stations the synchronous motors are operated by alternating current of 100 cycles per second taken out due to the interference of these two alternating currents.

Although it is possible to drive the picture drums by the use of synchronous motors only, D.C. motors directly coupled with synchronous motors are provided in the present system. The motor sets, respectively, for the sending and receiving stations are driven from independent batteries. The advantage of using the motors thus coupled together is that the greater part of the power required to drive the drums is supplied through the D.C. motors, the synchronous motors serving only to maintain synchronous operation. Compared with the case in which no D.C. motors are used, the current supplied to the synchronous motors in the present instance is very small, a contribution of about 10 per cent. of the total driving power being sufficient for stable operation, according to the writer's experience.

In order to detect the condition of synchronism a neon lamp is bridged across the A.C. terminals of the synchronous motor. The voltage to the lamp is the superposition of the voltage

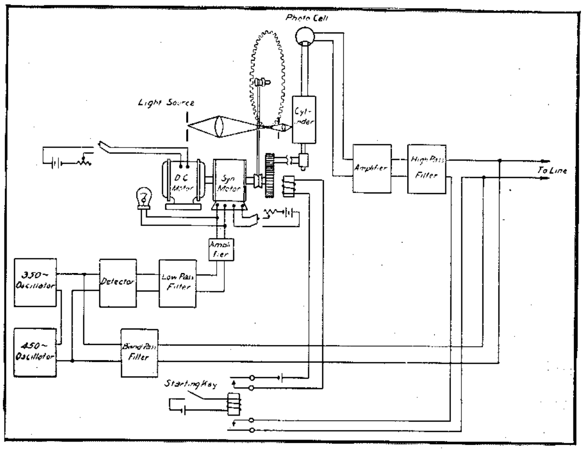

Figure 4—Sending System (Cable).

due to the synchronizing current and the induced voltage in the winding as a generator. If the motor runs in synchronism, the lamp lights steadily; while, if not, the lamp fluctuates with the frequency of slip and so synchronism can easily be detected.

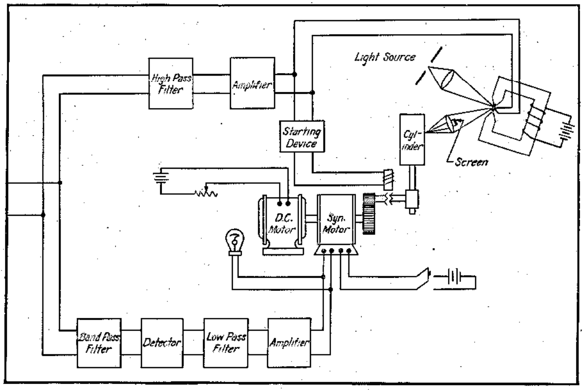

Figure 5—Receiving System (Cable).

The starting operation of the transmitting and receiving apparatus is controlled from the sending station. Accordingly, upon beginning the transmission of a picture, the drums are placed in their predetermined positions and the synchronous motor at the receiving station is started and synchronized by means of the synchronizing current from the sending station. After this, if the starting key at the sending station is closed, the sending drum starts revolving, being connected with the synchronous motor by an electrically controlled clutch. At the same time the picture carrier-current is sent to the receiving station. At the receiving station this current is amplified and detected and actuates a relay, thereby connecting the synchronous motor with the receiving drum, which then starts revolving. Thus the transmission of the picture is begun in correct framing as the sending and receiving drums are placed in proper predetermined positions. Also in this system it is not necessary to stop the motors after every picture for reloading, thus losing synchronism.

Comparing two methods of synchronous operation, the writer is of the opinion that, at least in the wired line, the use of synchronizing currents has decided advantages. Obviously, if the apparatus is run synchronously by a synchronizing current, care need be taken only of the operation of the synchronous motors at the sending and receiving stations and, as a consequence, the operation at both stations is greatly simplified. If, on the other hand, synchronous operation is performed by using a separate generator for the sending and receiving stations, respectively, it not only requires complex apparatus or mechanism, for instance, for the containers or driving mechanisms of the tuning forks in order to keep the generators to the required accuracy, but it also necessitates no small effort to maintain these apparatus or mechanisms properly and to check the two frequencies. Since these difficulties are entirely overcome by the synchronizing current method, its use appears to be of positive advantage in those systems from which it is not inherently barred by other considerations of theory, design or application.

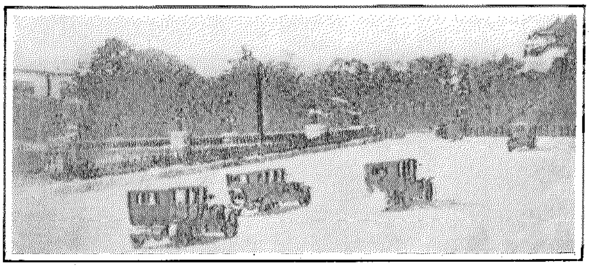

Figure 6—Picture Transmitted Without Filter.

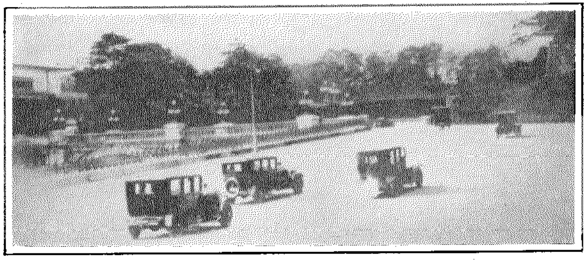

Figure 7—Picture Transmitted With Filter.

Some may argue that the sending of a synchronizing current increases current in the line, but this is of no practical disadvantage, since, according to the writer's practical experience in the use of this system, a telephone line has ample capacity for both the current used in the picture transmission and the synchronizing current, especially, if it is considered that the inducing effect of the synchronizing current with respect to other lines is, by reason of the low frequency of the synchronizing current, far less than that of the picture carrier-current. Also it may be contended that the use of a synchronizing current reduces the frequency band of the picture carrier-current and that, accordingly, in a system in which no synchronizing current is used, the frequency band of the synchronizing current may be included in that of the picture current, thereby broadening the latter band, and consequently rendering more accurate picture transmission possible. This view, however, is not correct, for even in the systems in which no synchronizing current is used, it is customary to generate picture carrier-current by projecting a pulsating light flux produced by interrupting a constant light flux by a rotating disc upon the film or the picture to be transmitted. When a pulsating light flux is used, two currents, namely, the picture current and the carrier-current modulated in accordance with the color-tone of the picture are generated superposed upon one another, as is evident from the above discussion. If it is desired to obtain a good picture, it is necessary to eliminate the picture current by the use of a wave filter. The synchronizing current, therefore, may be superposed in the frequency band of the picture current thus eliminated without reducing the frequency band of the carrier-current. If, for instance, the frequency of the carrier-current is 1,500 cycles per second, choice may be made of the maximum frequency of the picture current, as will be described later, so that it is 750 cycles per second, this frequency being selected as the cut-off frequency in order to get the maximum speed of transmission. Then, since the frequency band below 750 cycles per second is of no use for picture transmission, if the synchronizing current is superposed in this frequency band, the quality of the picture transmitted is not affected in any way, nor is the speed of transmission reduced. For the reasons above mentioned the use of the synchronizing current has been adopted in our present system.

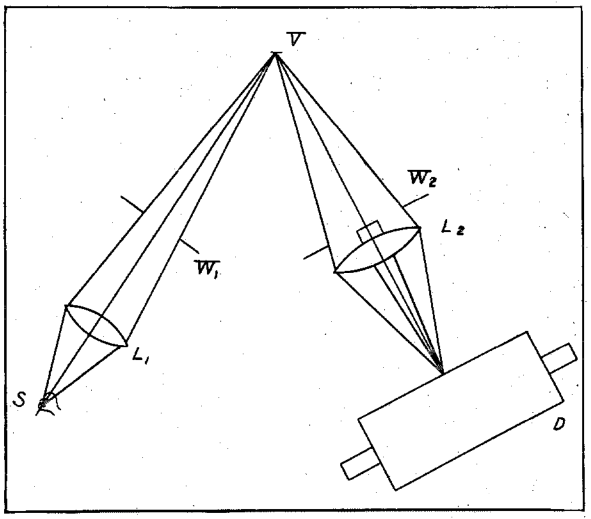

Figure 8

Receiving End

Thus, in the course of transmission, the carrier-current to transmit the color-tones of the picture is superposed upon the synchronizing current for maintaining the synchronous operation of the motor sets. These two currents, however, are separated by a wave filter at the receiving station, of which a schematic sketch is shown in Figure 3. The picture carrier-current is translated back by a vibrator type translating device into the color-tones of the picture, and the synchronizing current is used to operate the motor set at the receiving end in absolute synchronism with the corresponding set at the send-

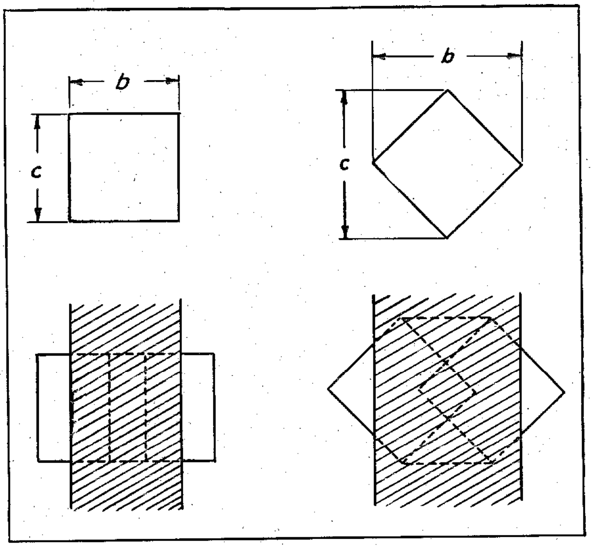

Figure 9

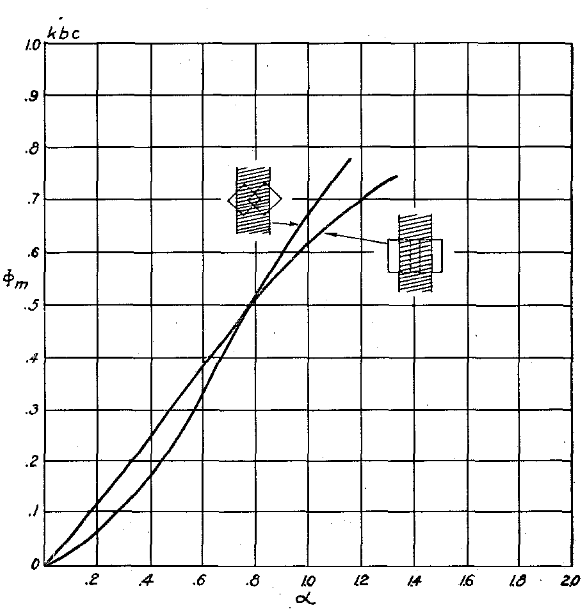

Figure 10

ing end, thus completing the picture transmission.

The main part of the translating device used in the present system consists of a combination of an electromagnetic vibrator and a screen as roughly shown by Figure 8. S is a source of light. The beams of light from this source are concentrated by lens L_1 upon mirror V of the vibrator, which is similar in construction to an ordinary electromagnetic oscillographic vibrator. W_1 is a screen placed in the path of the light. By changing the form of the opening in this screen the cross sectional shape of the light flux passing through the opening may be changed to any desired shape. Accordingly, the oscillating light reflected from the mirror V assumes a shape corresponding to the shape of opening in W_1. Now, if another screen W_2 is placed in the path of the oscillating reflected light and a part of this light is interrupted, the light passing through the second screen will bear a definite relation to the amplitude of oscillation of the light. In other words, the variations in current may be translated into variations of light. An important point regarding this translator is that various characteristics can be given to it by suitable arrangements of W_1 and W_2, and these arrangements may be roughly divided into the following two classes:

a. Central screened arrangement.
b. Side screened arrangement.

a. Central Screened Translator. We may consider two cases, for instance, in which the shape of the opening in W_1 is made a square and a parallelogram respectively, as shown in the upper part of Figure 9. When the light passing through the opening is reflected by the mirror V, it is evident that the cross sectional shape of the reflected light flux assumes the shape of the opening, if no current is flowing in V. W_2 is a band of such size that it just covers the entire reflected light flux when there is no current in V. If, however, a carrier-current flows in V, the reflected light flux oscillates to the sides as shown in the lower part of the figure, so that W_2 cannot cut off the entire light flux with the consequence that some of it passes through from both sides. The greater the amplitude of oscillation, the larger will be the amount of the light thus passed through from the sides. That is, since the greater the carrier-current, the greater will become the amount of the light, the light flux which passes through W_2 increases in amount for the white parts of the picture at the sending station. Thus, if a negative picture is transmitted from the sending station, a positive picture is received at the receiving station, and vice versa. If the shape of W_1 is altered, the color-tone of the picture received is correspondingly changed for the same picture transmitted. The relation which obtains between the light and amplitude when the shape of W_1 is varied may be found by computation or by experiments. Figure 10 shows characteristics for two shapes of the light flux. In Figure 10, α is the ratio of amplitude of oscillation to the width (b) of the

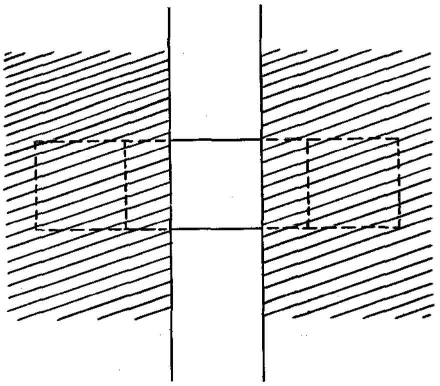

Figure 11

shape and the ordinate is the light flux in terms of the maximum light flux. Thus, it is seen that if a rectangular shaped light flux is used, a light flux, the amount of which varies in proportion to the amplitude of the oscillation, is obtained and that a light flux which very rapidly increases with the increase of the amplitude of the oscillation, is produced by the use of a light flux of the cross sectional shape of a parallelogram. Hence, for the same picture transmitted the picture received shows a more marked contrast of light and shade for a parallelogram-shape of light flux than for a rectangular shape.

b. Side Screened Translator. Considering the case in which the sides instead of the central portion of a light flux are screened off by changing the shape of W_2, Figure 11 may be taken for an example. If both sides of the light flux are cut off by a screen placed in the path, as shown by the figure, it is easily apparent that the greater the amplitude of oscillation of the light flux, the less will be the amount of light passing through the central opening. By choosing such a method as this a negative picture may be received by transmitting a negative picture, and a positive picture by transmitting a positive picture. The characteristics of this translator may be predetermined as mentioned above. In Figure 12 is shown the relation between the amplitude of oscillation and the light flux. This characteristic represents the case in which the size and position of the screen opening are so adjusted as to just pass the entire light flux when the amplitude of oscillation is zero. The horizontal axis represents the amplitude of oscillation in terms of the opening and the vertical axis the light flux in terms of its maximum amount. According to this characteristic the light flux is greatest when the amplitude of oscillation is least, the light value decreasing as the amplitude increases.

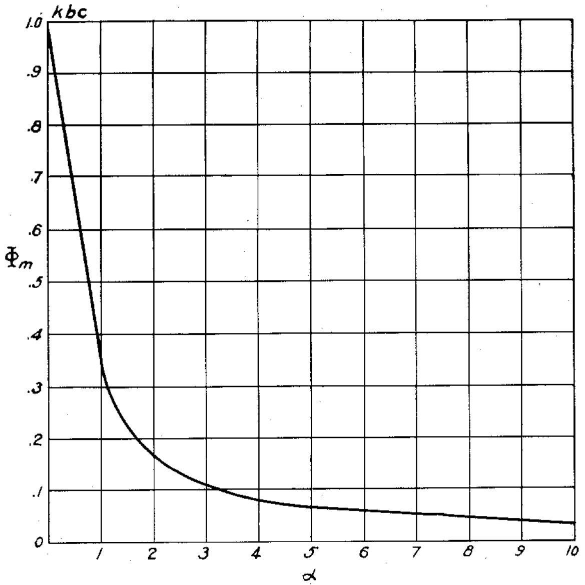

Figure 12

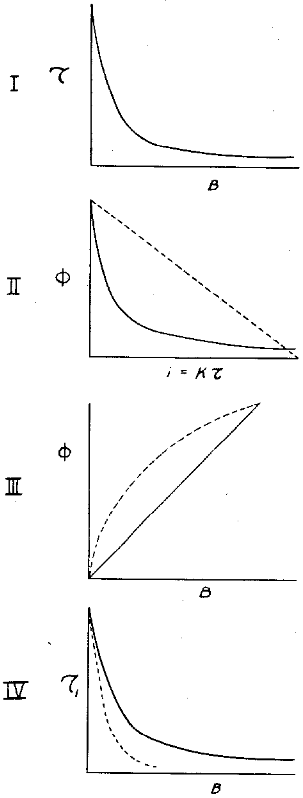

Figure 13
Negative to Negative

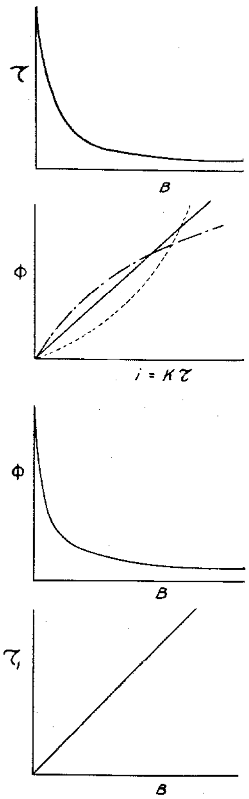

Figure 14
Negative to Positive

Translator Characteristics and Quality of Picture Transmitted

As picture transmission is nothing more or less than the reproduction, at the distant receiving station by electrical means, of pictures placed at the sending end, the characteristics of the translator should satisfy specific requirements in order to obtain ideal transmission. It is well known that a negative picture normally taken and developed has a transmission ratio which varies inversely with the light of the subject, as has been mentioned in the noted study by Hurter and Driffield, and a positive picture has a reflection ratio or a transmission ratio which varies directly with it. The characteristics required of a translator in order to obtain an ideal transmission from a normal picture at the sending end may be discussed as follows:

a. Negative to Negative Transmission. In Figure 13 curve *I* shows the characteristics of a picture at the sending station. B is the intensity of light of the subject and τ the transmission ratio of a negative film. If the negative picture has been obtained by a proper exposure, the curve assumes the shape shown by *I* as mentioned above. It was explained previously that from the sending end a current proportional to τ is sent out when such a picture is transmitted. It may, therefore, be assumed that the current at the receiving end is also proportional to τ, that is, $i = K\tau$, where i is the current at the receiving end and K a constant. If the characteristic of the translator is as shown by *II*, Figure 13, when i is translated back into light, then from *I* and *II* it is evident that the relation between the light coming out from the translator and the intensity of light of the subject will take a form shown by *III*, Figure 13. That is, since the light which is proportional to the intensity of light of the subject is projected upon the sensitized receiving film, the picture received is a complete negative as shown in *IV*, Figure 13. It is, therefore, necessary, when a negative picture is to be reproduced from a negative picture transmitted, that the translator should have a characteristic such as shown by *II*. The characteristic of the side screened translator, which utilizes the central portion of the oscillating flux produced by the carrier-current used in this system, satisfies the requirement of *II* and is sufficient for the purpose. If the translators, such as one utilizing a string galvanometer or the Kerr effect, having a characteristic shown by a dotted line in *II* is used, the negative picture received will assume a dotted line *W* and faithful reproduction cannot be obtained.

b. Negative to Positive Transmission. In Figure 14 *I* is the characteristic of a negative picture to be transmitted. If a translator having a characteristic shown by *II* is used, the relation between the light coming out from the translator and the intensity of light of the subject is as shown by *III*. Since the light coming out from the translator is proportional to the light which passes through the negative film at the sending station, the case is exactly like the printing of a picture, that is, the positive picture received has correct relation of light and shade as shown by *IV*. In this case it is necessary that the characteristic of the translator should assume the shape as shown by *II*, and this requirement is satisfied by the use of a central screened translator in which is cut off the rectangular central portion of an oscillating light flux produced by the carrier-current used in this system. In this case it is also possible, by suitably adjusting the shape of the screen-opening, to receive an over-exposed or under-exposed negative. When it is desired to receive

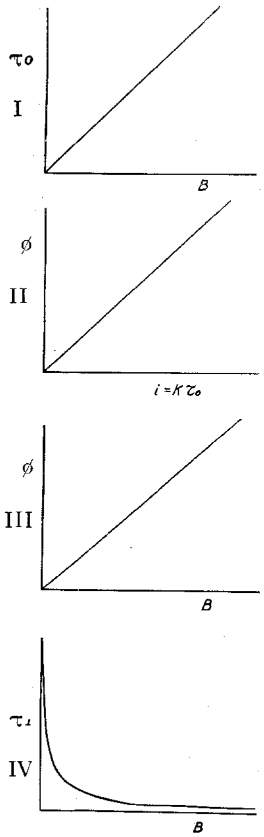

Figure 15
Positive to Negative

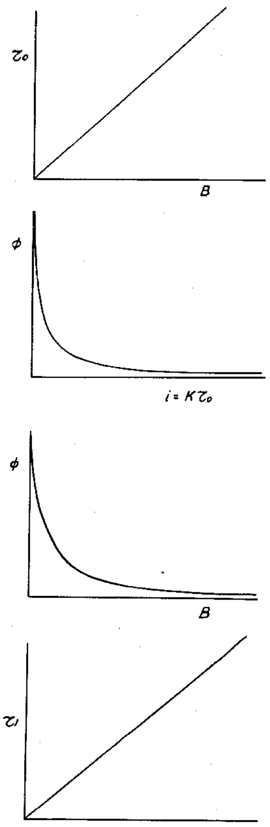

Figure 16
Positive to Positive

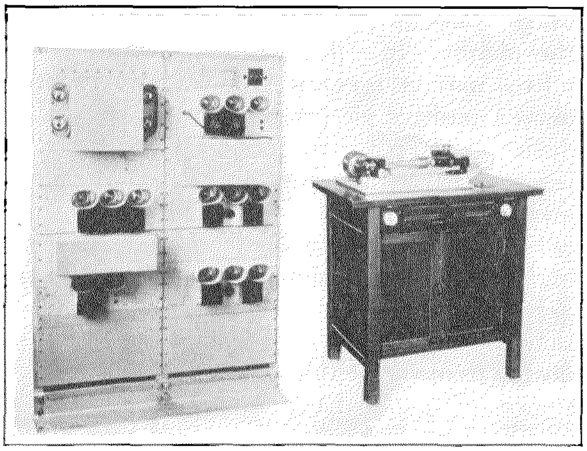

Figure 17

an over-exposed or under-exposed negative a characteristic as shown respectively by a dotted line or by a chain line in *II* may be used and in order to produce such characteristics it suffices to make the cross section of the light flux circular or parallelogram-shaped, as was previously mentioned.

c. Positive to Negative Transmission. Consideration may be given similarly to a case in which a good positive picture such as *I*, Figure 15, is transmitted. Since, if a translator having a characteristic as shown by *II* is used, the color-tones of the subject are transmitted unaltered to the receiving station, a good negative may be obtained by applying these to a sensitized film. That is, perfected transmission is attained if a central screened translator is used, in which the central portion of an oscillating rectangular light flux due to the carrier-current is cut off.

d. Positive to Positive Transmission. For this purpose a translator having a characteristic as shown by *II*, Figure 16, is required, that is, a side screened translator, in which the central portion of an oscillating light flux due to the carrier-current is cut off, should be used. In this case, also, as mentioned in the case of the negative-to-positive transmission, a translator having a straight line characteristic such as one utilizing a string galvanometer or the Kerr effect will not produce a good picture.

As discussed above, by the use of the translator of this system in which is utilized a vibrator actuated by the carrier-current, a picture may be reproduced in any desired form, positive or negative, at the receiving terminal by using a picture of either form at the transmitting terminal. The reproduction is perfect inasmuch as the original is perfect. Also over or under-exposed pictures may be perfectly transmitted by selecting the translator properly.

Reflection Method vs. Transmitted Light Method

The picture transmission systems now in commercial use employ either light reflected from the picture or transmitted light.

It may not be said that one system is better or more convenient than the other, since much depends on the kind of matter to be transmitted. For instance, if the picture is available in film form of proper size, the direct light method is preferable, whereas, if the positive only is available, and would otherwise require filming, the reflected light method is more convenient.

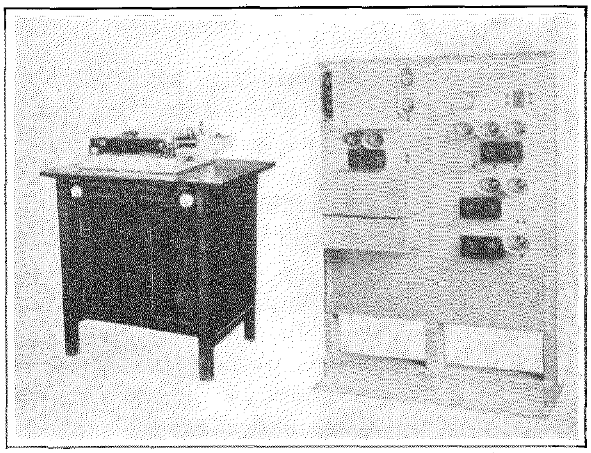

Figure 18

Since the limitation of the apparatus to either method would be decidedly inconvenient, it is desirable that an arrangement be employed permitting the use of either method at will. As to the quality of picture transmitted by the two methods, it may, in general, be said this depends on the quality of the original, either film or picture, at the transmitting terminal.

When it is desired to transmit a picture from its negative by transmitted light, excellent results may be obtained if the original negative is perfect. However, when a printed picture is to be transmitted by using the light reflected from it, care should be taken to get a perfect original picture by choosing the proper kind of printing paper and a suitable method of printing, depending on the nature of the negative. Some kinds of paper, such as "Velox" for example, have characteristics deviating from the Hurter and Driffield relation, and give very sharp pictures. Thus, considerable skill is required for the latter method of transmission which, however, may be employed in cases where it is desired to transmit a good picture from an unsatisfactory original negative by correcting on printing paper the lost tones in the original. Hence, in such cases the reflection method and printing paper like Velox may be used to good advantage.

In short, it is not possible to pass judgment in favor of either the reflection method or the transmission method solely from consideration of the work involved in the production of the original picture, the quality of the picture received, the degree of skill required in the transmission, etc., as the use of one or the other method alone is inevitably accompanied by some inconveniences. In the system described in this paper provisions are made at the transmitting terminal whereby a picture may be transmitted by using either the light transmitted through the film or that reflected from the picture. In either case the picture transmitted may be reproduced either as a negative or as a positive picture through the translating device at the receiving terminal, the characteristics of which are suitable both theoretically and experimentally for this purpose.

Figure 17 shows the photograph of the sending table and the amplifier and filter rack and Figure 18 those for receiving. In Figure 19 samples of pictures transmitted by light reflected from the picture or transmitted light are shown as compared to the original picture.

Speed of Transmission and Determination of Carrier Frequency

Here the writer wants to add a short discussion on the speed of transmission.

The maximum frequency comprised in a picture current is expressed by

$$f_p = \frac{n\,d\,l}{2} \qquad (4)$$

where n is the number of revolutions per second of the drum, d the number of lines per centimeter and l the length of the circumference of the drum or the length of the picture. If s is

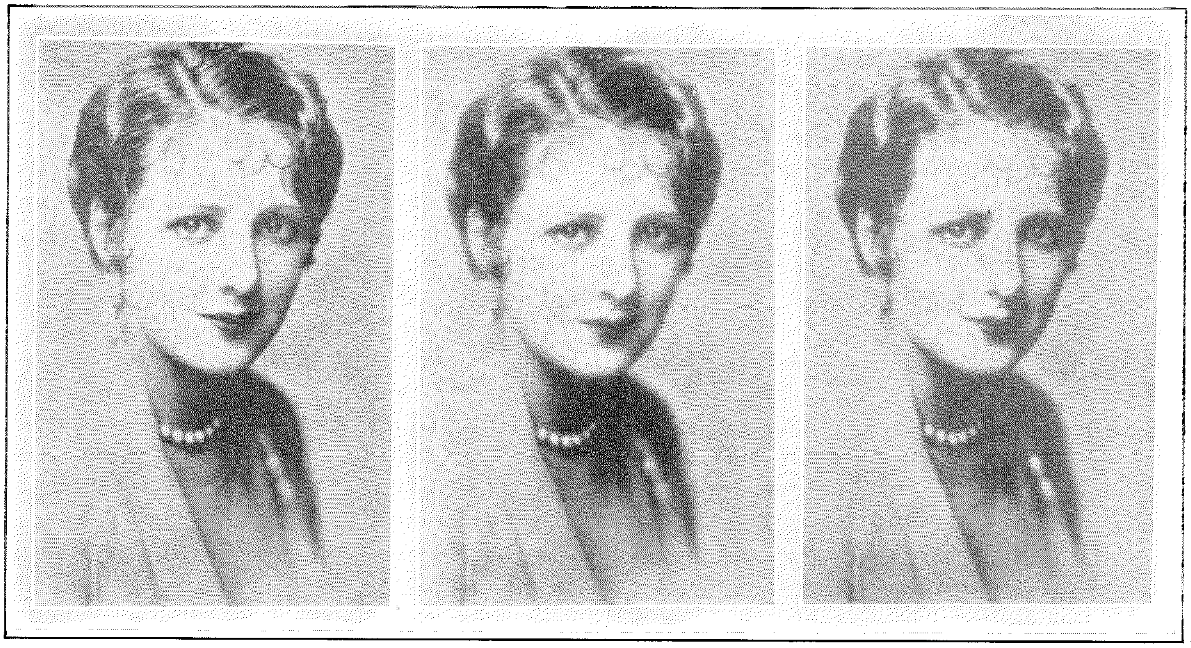

Figure 19—(a)—Original. (b)—By Transmitted Light. (c)—By Reflection.

the width of the picture, the time required to transmit a picture l centimeters long and s centimeters wide is

$$T=\frac{s\,d}{n}\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Combining these two equations and eliminating n,

$$T=\frac{sld^2}{2f_p}\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

is obtained. From this it is seen that the time required in transmission varies directly as the size of the picture and the square of the number of lines per centimeter and inversely as the maximum frequency of the picture current.

If f_c denotes the frequency of the carrier-current, the frequency band of the carrier-current modulated by the color-tone of the picture lies between f_c+f_p and f_c-f_p. Of these two values, f_c+f_p must lie within the frequency limits, say f_m, in which the medium of transmission works effectively. Since, in order to obtain a picture of good quality, it is necessary to eliminate the picture current of the frequency of the color-tone, f_c-f_p; must be greater than f_p. Thus the limiting values are

$$f_c+f_p=f_m,$$

and

$$f_c-f_p=f_p\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Out of these two equations we obtain the following relations for the maximum speed of transmission

$$f_p=\frac{f_c}{2}\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

and

$$f_c=\frac{2}{3}f_m\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Thus, if the maximum frequency permissible for the medium of transmission is fixed, the carrier frequency to be used to obtain maximum speed is determined by equation (9). Similarly, from equation (8) the maximum speed of transmission for a picture of a given size and of a given number of lines per centimeter is determined in accordance with the value of f_p chosen. As the present set now in practical use between Tokyo and Osaka is applied to the medium heavy loaded cable with a cut-off frequency of 2,800, we take f_m at 2,250, i. e., about 80 per cent. of the cut-off frequency, and therefore we get $f_c=1{,}500$ and $f_p=750$ to get the maximum speed transmission. As the number of lines per cm. is 80, the time required to transmit a cabinet size picture (ca. 10 cm. × 18 cm.) is about 13 minutes. The density of the line may be easily changed to 60 or 40 lines per cm. by altering the picture drum. The time required in such case is, of course, reduced proportionally to the number of lines. If the medium of transmission is open wire line and if the carrier frequency can be increased, the speed of transmission can, theoretically, be raised to the limit expressed in the equations (8) and (9). Practically, however, the speed is limited by mechanical or other considerations.

In the present system, vibrator type translator is used and so it may be feared that the natural frequency of the vibrator may cause a limit in the speed of transmission or impair the quality. Actually the natural frequency is far beyond the figure necessary for speedy and good transmission. The translator now in use has a natural frequency of 8,000 cycles and this, if necessary, can be raised to 20,000 cycles. Therefore, so far as the transmission of picture is concerned, this translator satisfies not only the necessary conditions for speed but also the requirements for quality as mentioned above.

Application to Radio

In the foregoing description the N. E. system for the electrical transmission of pictures is outlined. This system is being used in a wired system in connection with overhead lines and telephone cables, and the foregoing description is made chiefly in relation to this system. It is possible to apply this system without any modification to a carrier telephone or a radio system, as has been demonstrated by highly successful experiments. In this case it is sufficient to impress the output of this system after suitable amplification and regulation to the speech input of the wireless or carrier-current telephone equipment. In receiving, it suffices to impress the power thus transmitted, after it is detected, to the receiving device of this picture transmitting system. However, a wired system and a radio system present some inherent technical differences, and if the present system is to be applied to a radio system and worked efficiently, certain changes would naturally be introduced. For instance, whereas the writer firmly believes that it is more convenient for a wired system to transmit synchronizing current than to provide an independent oscillator at both the transmitting and receiving stations, in a radio system, in order to prevent the stepping out of synchronism of the transmitting equipments due to atmospheric disturbances, etc., separate oscillators should be provided, or else, if synchronizing current is transmitted, some device must be installed which easily restores the synchronism with respect to both time and phase when the equipments run out of step. Again, there are certain cases in which it is preferable not to transmit synchronizing current in order to effectively utilize the output of the radio transmitter. Although satisfactory solutions have been worked out regarding these details, these, in addition to the recent improvements such as gaseous discharge translator and high speed transmission, are left to a future paper, and the scope of this paper, therefore, is limited to the system in actual commercial use.

Supplement

As, during the six months following March of this year, when my main paper on the subject of picture transmission was completed, many notable incidents occurred, I wish to supplement my paper by mentioning the more important of these incidents.

In consequence of the Department of Communications' decision to open to the public the business of picture transmission between Tokyo and Osaka in 1930, and the adoption of the Nippon Electric System after a careful investigation on the part of the Department of Communications, the equipment to be used for this purpose is in process of manufacture, and probably in the spring of 1930 the first public picture transmission offices will be opened both in Tokyo and Osaka. Regulations as to charges, the kinds of pictures to be handled, etc., have not yet been published.

This government business of picture transmission between Tokyo and Osaka over the distance of 577 km. will be carried on by both aerial telephone lines, consisting of 4 mm. hard drawn copper wires and the phantoms of 4-wire medium heavy loaded repeatered circuits. For the aerial lines 6,000 cycles is adopted as the frequency of the picture carrier-current and 200 cycles as that of the synchronizing current. As for the size of pictures to be transmitted, any size up to 18 cm. x 26 cm. may be used, and the time required for transmission is approximately 6 minutes when a maximum sized picture is transmitted at the line density of 60 lines to the centimeter. Conversation may be carried on between the two terminals, while a picture is being transmitted. Repeater equipment is installed at Nagoya (situated 378 km. from Tokyo) to amplify the picture carrier-current exclusively, provision being made to by-pass both synchronizing and speech current. This repeater equipment is so designed that it may be operated as desired from either Tokyo or Osaka. Of course, a phase compensator is provided at each terminal. For the cable circuits 1,700 cycles are used as the frequency of the picture carrier-current and 300 cycles as that of the synchronizing current. The time required for transmission is approximately 20 minutes when the size of the picture transmitted is 18 cm. x 26 cm. and the line density 60 lines to the centimeter.

In the equipment described in my main paper for starting of operation and framing, the receiving drum was started from the sending terminal. But, since, according to such a method some inconvenience is introduced due to the deviation in the operating time of relays, etc., the improvement mentioned in the following has been effected.

When a picture is to be transmitted, the drums at the sending and receiving ends are caused to rotate in synchronism, but the drums are so constructed that they rotate without feeding axially until the operators engage the feeding mechanism. To accomplish proper framing, the dead angle of the sending drum is utilized. Each time this dead angle is reached, *i. e.*, once in each revolution, the carrier current is interrupted, causing a corresponding stop in the vibration of the translator at the receiving end.

The image of the vibrator mirror is projected onto a rotating disc geared in proper ratio to the receiving drum and having a projecting marker at a point corresponding to the dead angle of the receiving drum. When the sending and the receiving drums are in phase, the image from the mirror will fall upon the marker, and this condition is effected, and proper framing accomplished by gradually rotating, by hand, the stator of the synchronous motor. This starting method is also applied to the set used with cable circuits.

In the picture transmission system as developed for radio, independent synchronization is used. The tuning fork at each of the sending and receiving terminals is put into a specially designed box, which is provided with a thermostat, and maintained at a constant temperature. In order to detect the degree of coincidence of the synchronizing frequencies at both the sending and receiving stations, a certain harmonic of the synchronizing current at the sending station is transmitted as a radio wave to the receiving station where, by the use of a special harmonic producer, the thirtieth harmonic of the synchronizing frequency is taken out. This harmonic is detected after it is made to beat with the corresponding harmonic of the synchronizing current at the receiving station. When this method is used, it is possible to tune the frequencies at both stations in a few minutes. The equipment employed is the same in other respects as the one we have heretofore been using. The time required for transmission is approximately one minute for the cabinet size.

Rapid Toll, Suburban and Rural Automatic Telephone Services in Tuscany

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THE proportionate use of the telephone marks the trend of a nation's commercial and industrial prosperity. In Italy, although much leeway in telephone progress has yet to be made up, there are signs that development will now proceed more rapidly, for figures already show a hopeful annual increase of subscribers.

If this increase is to be maintained, the present policy of providing urban districts with automatic service, and abandoning the less important suburban and rural centres to an imperfect manual system, will have to be seriously reviewed.

The present telephone organisation appears to have been established upon the assumption that urban districts alone can supply the necessary volume of traffic. Around them has been built up a complex system of toll operation, necessitating a string of operators specially detailed for this particular service. Such an organisation can hardly be expected to devote much time or consideration to the needs of suburban or rural communities where low traffic and small revenue prevail.

Small urban centres and rural districts are likely to be regarded as accessories and of little interest to an operating company. They are relegated to a secondary position, and in most cases they owe their existence to an operator who has other duties—of more importance, and certainly more remunerative—to perform. Hence, with indifferent quality of service during the day, and with total cessation of service during the night, the inefficiency of the rural system becomes an accomplished fact.

Such were the conditions of suburban and rural service at the time the Società Telefonica Tirrena were called upon to undertake re-organisation in Italy. The Societa were careful not to fall into the grooves of precedent. The common arguments levelled against rural automatic telephony were carefully weighed and were found wanting. It was discovered that by judicious amalgamation and treatment of two or more districts as a homogeneous unit—to raise the total number of subscribers and consequent traffic density—a satisfactory solution of the problem would result, fully meeting technical and economical requirements.

This method has been successfully applied to the districts of Tuscany, Liguria, and Lazio. Accepted principles in telephone network formation, as exemplified by present urban service, have had to give place to a wider perspective embracing a network of urban, suburban, and rural districts, the configuration of which comprises a Main Traffic Centre to which the suburban and rural centres are subordinated, and through, or to which, the greater part of the traffic passes. As an alternative, there may be a District Centre with a group of radial junctions having direct or indirect connection with one or more of the intermediate centres, as will be explained later.

For greater zones, the same configuration is maintained by further subdivision at the various centres, the whole assuming the form of a self-contained unit with a main exchange at its centre.

Where the topography of the district is of a special character, or where special traffic conditions are encountered, certain departures from this general formation may, of course, be necessary; but in any case the maximum distance between the main centre and any of the subordinate centres will not exceed 25–30 Km.

Districts of this description will not be characterized as in the past by a series of individual exchanges, each working independently of each other, and only inter-related by a complicated toll network, necessitating the introduction of a train of manual toll operations and special staff.

The network scheme under the consideration of the Società Telefonica Tirrena aims at a single main automatic centre, serving urban, suburban, and rural districts, with a single numbering scheme, a single method of selection, and a single quality of service for all, regardless of the extent of the district or of its ultimate capacity in lines.

The district will, therefore, constitute a homogeneous switching unit, supplying a standard quality of service both to the urban mansion and to the village cottage.

More than a year and a half of research work, in collaboration with the leading manufacturing companies, has been expended in the solution of problems, now to be described, connected with the production of a system to fulfill the needs revealed by this reorganisation work.

In any particular district there can be either a flat rate call or a metered call. The first class is applicable to zones within the limits of which a subscriber can obtain an automatic call regardless of distance or duration. It thus resembles any local connection in an urban district with flat rate service.

The second class is applicable when any subscriber in one zone effects a call to another subscriber in another zone. In this case, the call is charged in accordance with the distance separating the two parties and the duration of their conversation. The two factors that determine the charge—i. e., zone and time—vary considerably.

The problem in this case is complicated by the fact that it calls for means of discriminating between districts enjoying full automatic service and those with semi-automatic service. Where full automatic service is in operation in a whole district, two subscribers, although they may not even belong to the same zone, may obtain connection by simply dialling the wanted number. But in this case, the calling subscriber's meter will not register one, but a predetermined number of calls in accordance with a rate based on the distance separating the two parties and the length of their call. This multimetering is effected by a special register, which measures the distance between the two parties, and a control clock which transmits to the register a given number of current impulses corresponding to the duration of the connection. The distance separating the subscribers is determined by the block of subscriber numbers assigned to them. A single numbering scheme throughout the district, and the subdivision of this numbering into zones, in order to obtain the required meter charge, make this possible. An area with a capacity of 9,999 subscriber numbers, for example, with a uniform numbering scheme, could be divided into three zones, as follows:

1st zone: 1,000–3,999
2nd zone: 4,000–7,999
3rd zone: 8,000–9,999

A call of the second category, for instance, would thus cause the register to meter the originating subscriber with "x" meter units for the 4, 5, 6, and 7 thousands (in case the call was for the 2nd zone), and "y" meter units for the 8 and 9 thousands (in case of the 3rd zone). The same register discriminates and translates the current impulses transmitted to it by the master clock, to determine the length of the conversation.

This method of rating is of course limited to multiples of the meter unit, and although the inflexibility of the system may be overcome in some degree—by distancing the impulses on the master clock to reduce the fee during hours of low traffic by one-half or one-third of the unit rate, for example—it remains nevertheless a fact that the system must still be based on multiple figures.

A similar scheme has been introduced into Switzerland by way of experiment, but its adoption has not been considered suitable in Italy for the following reasons:

(1) The present rates would not compare favourably with those introduced by time and zone metering, and the application of this scheme was considered too rigid for present purposes.
(2) The automatic equipment for time and zone metering is at present so expensive and complicated that its introduction is not economically justified.
(3) Automatic metering only gives a total figure reading on the meter, and consequently if a subscriber should at any time contest his telephone bill there would be no means available for proving that it is correct.

These considerations weighed in favour of the adoption of a semi-automatic service for the time being, and the semi-automatic was finally

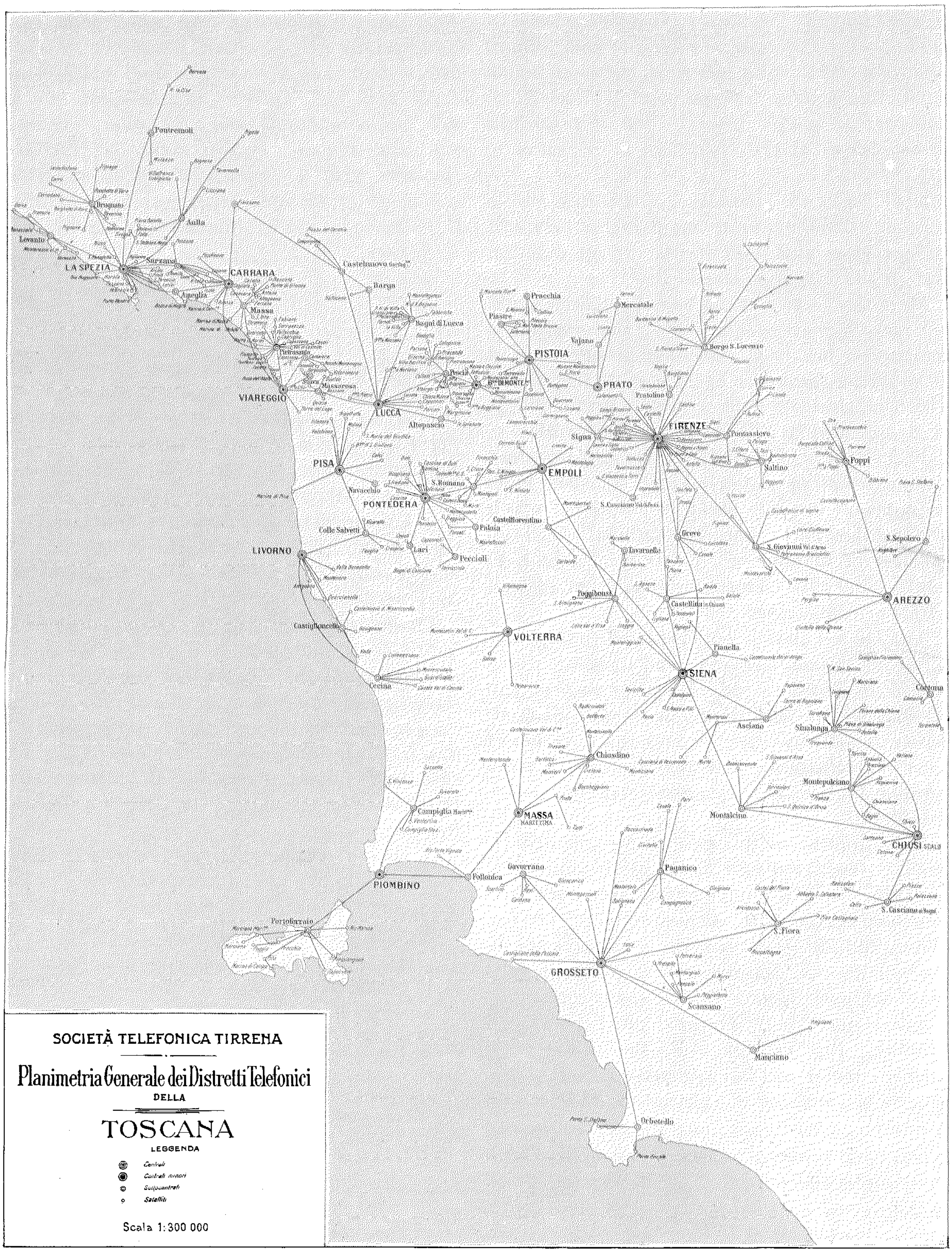


Figure 1—Tuscany Toll Lines.

decided upon for the Tuscany area. With this method, a toll manual switchboard is provided in each district centre, equipped with toll lines for inter-district traffic as well as suburban lines for automatic rural centre traffic in the same district. It is thus possible to meter all calls according to zone and time manually. Provision has been made, however, for the introduction of automatic zone and time metering whenever this may be required.

The rural automatic centres are divided into two kinds:

(a) *Automatic Rural Centres.* These centres are provided with full automatic service for connection of regular lines, automatic P.B.X. lines and satellite exchanges, for flat-rate connections to the urban system, or metered connections to the suburban system.

(b) *Rural satellites.* These satellites are provided with full automatic service for connections with urban and suburban subscribers.

The automatic equipment in the district main centre is similar to that in the service of urban districts for regular subscribers, public call stations, urban satellites and P.B.X. stations.

The main characteristic of special note, in connection with the main centre equipment, is the provision of a single manual toll switchboard for the control of meter charges to its own local traffic as well as outgoing traffic to other districts. It also provides means of supervision for the service in general.

The network is composed of a series of automatic junctions between the urban and rural centres in a given district, the districts themselves being inter-related by means of a series of toll lines over which outgoing and incoming calls are effected and metered accordingly.

The abolition of toll recording, with its inherent delay in service, which most certainly would have been introduced if the network had been planned on past conceptions, marks the first step towards a new outlook in operating methods, and has given the necessary impetus to the creation of rapid toll and rural automatic service. At the present time all toll lines in Tuscany are operated on the "rapid toll" basis, including even a few of the important trunks of inter-regional networks, by way of experiment.

Rapid Service

"Rapid service" allows for automatic control of a telephone connection over any physical or phantom circuit, repeater equipment or otherwise, which connects two automatic exchanges or an automatic exchange and a manual switchboard, irrespective of the distance separating them.

To Comm. del Pino is due not only the introduction of the "rapid service" system in Italy, but many innovations incorporated into the T.E.T.I. organisation. This aims at the extension of town automatic facilities to districts of lesser importance, by creating a single telephone system throughout the area without distinction as to the size and importance of the various centres. The pioneer work of this new and important development in automatic telephony is being undertaken in Tuscany.

Telephone Districts in Tuscany

The complete telephone network of Tuscany has been split into 19 rural districts as shown in Table I. These are interconnected by toll lines as illustrated in Figure 1. The radial networks interlinking the various minor centres with the main centre are illustrated in Figure 2, which also shows the whole network in active course of construction.

Automatic Exchanges

The automatic exchanges of the various urban and rural centres of the district were provided with initial equipments in accordance with requirements for their respective local and junction traffic. An automatic exchange may be reached by more than one district centre. The initial equipments are uniform to suit the standard sizes of the manufacturing companies, but ample provision has been made for future extension.

The Società Tirrena had adopted as standard the following methods of automatic connection and apparatus:

(a)	Regular connections over a subscriber line.	
(b)	1— 1 (duplex).	Two-party line connections with secret service.
(c)	1— 1 (bridged).	Main line set and extension set with possibility of local connections between them.

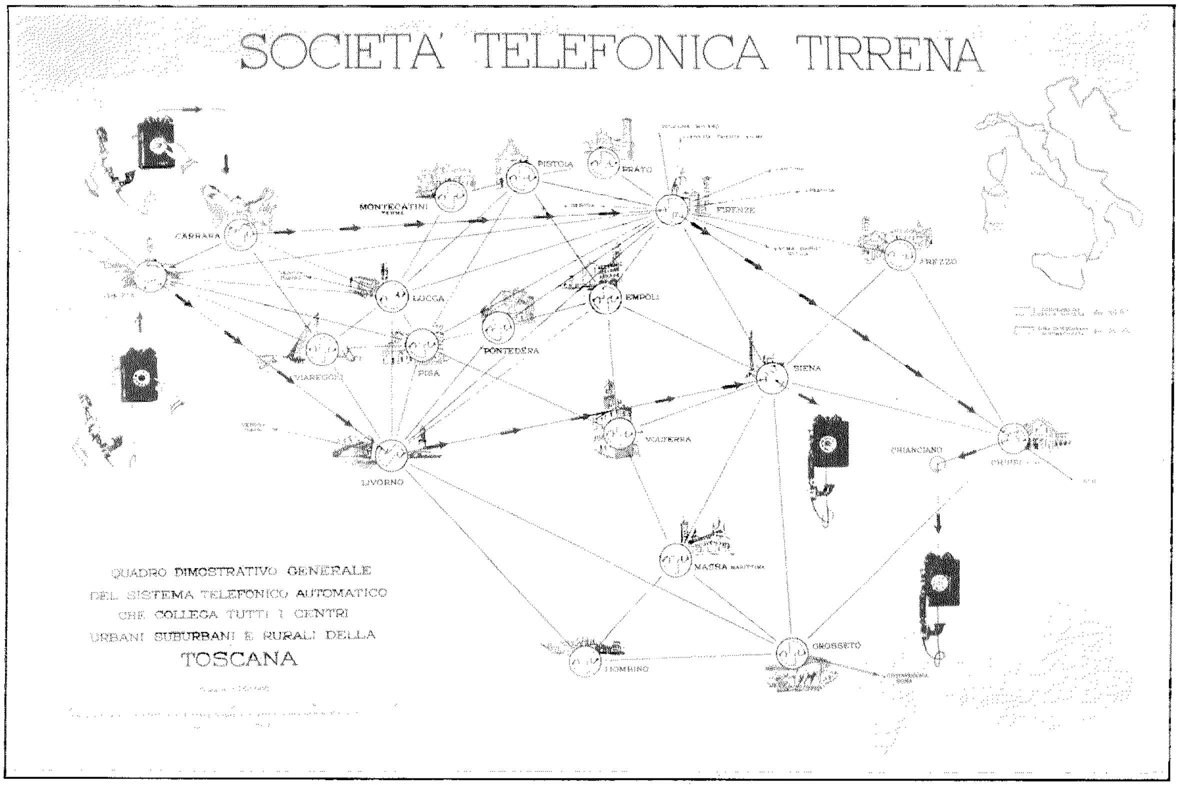


Figure 2—Radial Networks in Tuscany.

(d) 10— 1 (multiplex). Automatic P.B.X. with 10 extension lines and one junction, but without facilities for local connections between the 10 extension lines.

(e) 10— 3 Regular automatic P.B.X. for 10 extension lines and 3 junctions.

20— 4 Regular automatic P.B.X. for 20 extension lines and 4 junctions.

30— 6 Regular automatic P.B.X. for 30 extension lines and 6 junctions.

50—10 Regular automatic P.B.X. for 50 extension lines and 10 junctions.

100—20 Regular automatic P.B.X. for 100 extension lines and 20 junctions.

For communities of over 100 subscribers, regular exchange equipments are provided.

Exchange Initial Equipments

In order to appreciate fully the importance of the undertaking, Table I, showing initial equipments of the various exchanges, may be examined.

District and District Number	Exchange number of lines.	Toll Exchange number of lines.	Number of Rural Centres.	Number of Satellite Exchanges	Total initial capacity of Rural Centres Lines.	Total initial capacity of Satellite Exchanges Lines
1. Firenze	9,000	100	3	22	253	732
2. Prato	1,000	32	2	4	77	8
3. Pistoia	800	24	1	16	12	206
4. Montecatini	700	16	1	19	330	195
5. Lucca	1,100	24	3	24	462	339
6. Pisa	1,300	32	1	10	23	166
7. Livorno	3,000	32	2	15	78	183
8. Viareggio	800	24	2	13	700	437
9. Piombino	330	12	1	14	55	320
10. Volterra	120	16	1	15	55	186
11. Massa Marit.	120	8	2	12	110	94
12. Grosseto	330	24	3	11	101	228
13. Pontedera	330	24	3	24	111	379
14. Empoli	550	24	3	26	165	394
15. Siena	1,000	24	7	28	331	383
16. Chiusi Scalo	330	16	4	17	188	292
17. Arezzo	550	24	2	24	165	233
18. Carrara	800	24	3	21	990	648
19. Spezia	1,400	32	3	25	165	369
Total	23,560	512	47	340	4,371	5,792

Multi-Control

The control of an exchange from various centre exchanges merits special attention.

(a) Where the selection of an automatic exchange is under the control of one or more districts, it follows that the numbering in each district must be the same. If, for example, the automatic exchange is provided for four digit selection, these four figures must be exactly the same as the last four digits used by centres with five or six digit dialling.

(b) When the satellite is controlled from more than one automatic centre, which although infrequent is not impossible, the numbering of the satellite lines must be identical with that in each of the centres from which they are controlled for selecting purposes.

(c) Multilateral control must afford a means of connecting, for example, an automatic exchange either to a district with flat-rate service, or to a district with multi-metering service, so that the control gives to the system a greater measure of flexibility than in the case of a manual system.

Toll Switchboards

The toll switchboards may be considered as one of the most important features of the installation, as it is through them that control is kept on the payment of calls passing between one district centre and a suburban centre.

In their initial stages, the toll positions have been provided with the quantities as given in the above total, but they are arranged to extend to three times their present size. Each operator's load is not limited to the traffic originating from a certain number of toll or rural lines, as in the past, because as will be explained later, the traffic on reaching the toll board is evenly distributed over all the operators with a view to avoiding the necessity of a separate recording service.

Concentration between the various positions is foreseen, however, and care is taken to adjust the number of operators to the requirements of the traffic during the different hours of the day. Besides this arrangement there is a further method of concentration which, from many points of view, may be considered of more importance. This is in connection with the rapid automatic toll service between the toll switchboards of the various districts. If, for example, the district of Viareggio should be found to handle an insignificant toll traffic during winter months, this traffic could be switched by means of the Viareggio-Pisa toll lines to the Pisa toll switchboard, from whence it may be temporarily handled. A similar method of concentration is provided for other districts.

Dialling from the toll switchboard to automatic exchanges over rural or toll lines is usually effected by means of alternating current (A.C.) impulses in order to make use of the phantom circuits, and to ensure correct connection between distant centres.

In some cases, and especially where short lines are in existence, direct current (D.C.) impulse dialling over phantom circuits is in use, but this system is not generally favoured.

The face equipment of a district toll switchboard does not present much similarity to that of the generally accepted equipment, inasmuch as the former must include equipment possessing the following characteristics:

(a) Toll lines equipped for long distance A.C. dialling over physical or phantom circuits with both-way service for the control of metered toll connections between the various district centres.
(b) Rural lines equipped for long distance A.C. dialling over physical or phantom circuits with both-way service for the control of metered rural calls with rural centres of the district.
(c) Outgoing urban junctions for D.C. dialling for control of the urban traffic of the district centre.
(d) Regular toll lines for both-way service with jack, relay, and lamp equipment for lines not appertaining to the rapid service.
(e) Regular incoming recording lines from the automatic exchanges.

The corresponding equipments at the district automatic exchange end are as follows:

(f) Regular lines for subscribers and public call stations with the flate-rate service.
(g) Junctions to rural exchanges or urban satellites working on the flat-rate service.
(h) Incoming toll lines for inter-district connections as explained under (a).
(i) Rural lines from the toll switchboard for connections from other districts to rural centres.
(j) Urban junctions incoming from toll switchboard, as (c).
(k) Recording lines outgoing to toll switchboard.

Inter-District Trunk Routing

Two methods of routing are provided for rapid toll calls between the districts.

(a) *Direct inter-district dialling.* When district "A" is directly connected to district "B," the toll operator at "A" can dial over a special line the "B" automatic exchange without the introduction of any intermediary switching point. This arrangement provides very rapid service between the districts. The method is only applicable to very long lines where the traffic density is sufficiently important to compensate the high cost, or on the other hand, on short lines, as for example, between two neighbouring districts.

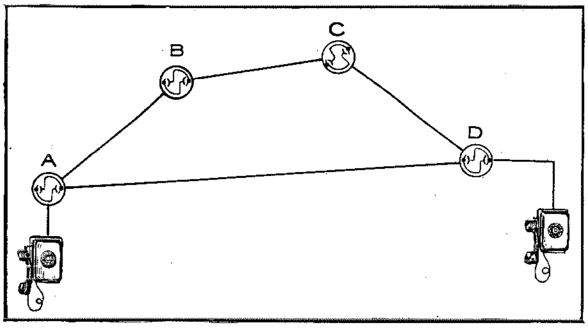


Figure 3—Indirect Inter-district Dialling.

(b) *Indirect inter-district dialling.* Where two centres are a great distance from one another and where, moreover, the amount of traffic is insufficient to justify the establishment of direct junctions between them, or where the existing direct junctions are all busy, a call can be effected by indirect or tandem operation. In order to make this point clear, reference should be made to Figure 3, which illustrates four districts, A, B, C and D, arranged in circular formation. From this it will be clear that calls between A and C and B and D cannot be effected without passing by B and C, respectively, and that when all the direct junctions between A and D are engaged, a further call between the two centres A and D cannot be made without passing through B and C.

To give effect to this method of routing a call, it is thus necessary that all groups of inter-district trunks should be accessible to the toll position for direct calling, and to selective equipment in the automatic exchange centres for indirect calling, as follows:

When the toll operator of A wishes to call the automatic exchange B, she plugs in on the associated trunk group AB and dials the desired number. Now, a certain number of outlets in the selecting field at B are connected to the trunk group BC, which can be reached by dialling a predetermined number of one or more digits.

For example, the A centre may have access to the group of trunks BC over the xy level, after selection of which, a further selection will extend the call to a level reserved to the CD group of trunks in the following exchange, and thus the D exchange will be reached. By this means, the problem of tandem operation is completely solved, and offers an almost unlimited method of inter-district connection. For practical purposes, however, it is not advisable to go beyond two or three successive stages of tandem selection.

Tandem trunking of inter-district calls brings with it a certain complication in switching equipment which is counterbalanced by greater trunk efficiency than exists with direct trunk working. Direct trunking, as before stated, is now almost exclusively limited to long distance lines with heavy traffic, or to short lines between neighbouring districts.

Method of Operation

The above explanation will now make clear the method of operation which is being employed for district service.

(a) *Automatic exchange of the district centre.* A local subscriber of the district centre who wishes to call another local subscriber or an urban satellite subscriber, dials the relevant number in the usual manner. If he should desire a toll connection, or a rural exchange subscriber, he dials the digits "01" and is thereby connected to the operator, to whom he communicates the wanted subscriber's number.

(b) *Urban satellite exchange of the district centre.* The method of operation of the subscribers connected to this satellite is the same as that of the district centre without any abridgement of the service facilities offered.

(c) *Rural centres.* Upon the subscriber making a call, his line is automatically connected to a connecting circuit. A "dialling tone" is received by the calling subscriber, who thereupon dials the digits of the wanted number. These digits are always dialled in full, even when the call has to be handled by the suburban operator. If the wanted party pertains to a flat-rate zone, the call goes through automatically. On the other hand, if the call should be destined for another zone, it is routed by the suburban operator, who makes the required connection and meters it according to the charge.

(d) *Rural centre satellite.* Upon the subscriber making a call, his line becomes automatically connected to a junction to the rural exchange. The subscriber receives the dialling tone, or if the junctions to the exchange are "busy," he receives the "busy tone." If the number dialled by the calling subscriber is that of another subscriber of the same satellite, the line of the calling party first becomes connected to a local junction circuit, but upon the called subscriber answering, the junction line is freed. The same methods are applied to a local call in a rural centre.

(e) *Toll exchange.* The toll operator desirous of calling a district centre subscriber or district centre satellite subscriber plugs in on one of the urban junctions. Upon receiving the "dialling tone," he dials the wanted party's number. When the call has been established, he can recall the subscriber by depressing the calling key. If the subscriber is busy, the operator has facilities for listening-in and can advise him of the toll call and afterwards break down the local connection.

To call a subscriber connected to a rural exchange, the operator plugs into a free junction connected to the exchange. After receiving the "dialling tone" the operator dials the wanted number. If the subscriber is busy, the operator can listen-in on the local call and, if necessary, break it down. On the other hand, if the line is busy on a toll call, the operator receives a busy tone signal and in this case the breakdown of the connection is not possible. The same procedure is followed in connection with the establishment of calls to rural satellite subscribers.

Regarding calls for subscribers outside of the district, it has already been explained how they are effected by direct and indirect trunking.

New Principles in Automatic Telephony

It is no exaggeration to say that the introduction of automatic telephone service in Tuscany has created altogether new principles in the field of automatic switching on a large scale. To demonstrate this, it will suffice to glance at the conditions which prevailed before the work of the Società Tirrena had been started.

(a) *Single numbering in each district for automatic control of all connections.* The single numbering scheme replaces the numerous independent numbering allotments which were heretofore assigned to each large or small centre, and eliminates the necessity for distinguishing by a special prefix these centres one from another.

Today, the only prefixes retained are those in connection with the various districts, which total in all 19 for Tuscany, 5 for Liguria, and 6 for Lazio, giving a grand total of 30 prefixes for the whole of the Fourth Zone, in place of the thousands of prefixes which before obtained. As an illustration, consider the subscriber number "85728 Firenze." This is the only subscriber in the whole district with such a number, whether he pertains to the city of S. Giovanna or Vallemoso, and no further identification is required of him other than the name of the district "Firenze," which distinguishes him from subscribers having the same number in other districts.

A single numbering scheme throughout the district affords a single method of selection, and also eliminates all special intermediary services. With the absolute precision of automatic switching, it is possible to obtain not only the wanted subscriber's line, but discrimination between non-metered and metered calls, trunk offering and breakdown for toll calls, listening-in and any other service requirements.

The only special service retained for the time being is the recording service. This is for economic reasons, as in view of the high cost of long distance telephone lines, it has not been found possible to supply a sufficient number of direct trunk routes necessary to obtain even a normal waiting time during hours of maximum traffic. Thus, if the scheme without recording service had been followed, it would have given rise to inconvenience, such as a subscriber making repeated efforts for his call while another subscriber, seizing the junction just at the time it became free, would obtain unjustified precedence.

To avoid dissatisfaction in this connection the recording service was retained for the present time, but it is already being planned to substitute switching equipment to handle automatically these calls in their order of sequence. This method of working will be put into force as soon as it is decided to adopt full automatic operation throughout the network.

The recording service itself, however, has undergone radical changes, inasmuch as both the recording and toll lines are now supplied with calling and busy lamps and are multipled over all the operators positions, so that upon the appearance of a call the first free operator can reply and handle the connection direct from his position. In this manner, the waiting time is practically reduced to nil in all cases where a free trunk is available, and is reduced to a minimum in the case where all trunks are momentarily found busy.

(b) *Metering arrangements.* As previously mentioned, the manual method of registering calls has been retained in Tuscany instead of automatic time-zone metering, since the latter does not provide the operating company with adequate safeguards against complaints from subscribers. This consideration has affected the design of the automatic register which, however, arranges for the discrimination between local zone calls, where no metering is necessary, and for calls where manual metering is required.

(c) *Register functions.* Other features of the automatic register are as follows:

(1) *Register as translator.* The register receives a train of impulses and modifies or translates them into other trains of impulses in accordance with prearrangement.

(2) *Register as selector.* The register receives the impulses dialled, and sets up the train of switches for the selection of the wanted party's number.

(3) *Register as a by-pass.* Where a call does not engage the whole train of local switches in one exchange, the register releases those that are not required so as to reduce the switch holding time.

(4) *Register as director.* This is an arrangement whereby the register is enabled to augment or absorb certain of the impulses received from the dial so as to add or eliminate certain stages of switching with a view to the selection of the most economical routing of the call.

(5) *Register as interceptor.* An arrangement which restricts the establishment of certain connections whenever the caller is not authorized to make such calls, in which case the said call is diverted to an operator's position, who advises him accordingly, or he is otherwise advised by a special tone.

(d) The inter-district service has already been described, as well as:

(e) The multi-control of the automatic centres. These two fundamental features of the T.E.T.I. system contribute more than anything else to the great flexibility and economy of the telephone network.

(f) The various tones for dialling, busy condition, etc., are considered to be of great importance by the Società Telefonica Tirrena, particularly the discriminating ring used in connection with toll calls. It is required that the discriminating ring operate with greater frequency in order that the subscriber will answer this type of call more promptly, with consequent speeding up of the service.

(g) The trunk offering and breakdown of local connections in favour of toll calls are methods of operation already established in Italy, and it is assumed that, with the increased development of the toll network, the necessity for the breakdown feature will eventually disappear.

(h) Distant metering control with consequent engagement of junctions purely for this control is necessary for the economical utilisation of the lines during the initial period of the service.

(i) Alternating current dialling over rural and toll lines was adopted, not only to make use of the phantom circuits, but because such a method possesses a factor of security on long distance lines, far in advance of a system using direct current.

(j) The operating personnel attached to the automatic installation of the T.E.T.I. system is very small, and generally confined to the district centre exchange. They are required primarily in connection with the operation and maintenance of the manual switchboard in each of the district centres. The various automatic exchanges in the district are only visited periodically for routine maintenance, and in exceptional cases where an alarm transmitted from the rural exchange to the control desk in the centre exchange indicates need for such a visit.

(k) The charging of the batteries in the automatic centres is effected automatically, and can be regulated from the district centre over junction lines.

(1) Faults developing in the rural centres are also automatically signalled in the district centre exchange, by the closure of alarm circuits over junction lines.

(m) Faulty equipment is automatically cut out of service, as well as calls originating over defective subscriber lines.

(n) The supervisory positions of the toll switchboard in the district exchanges have been arranged to provide for various special service calls such as information and complaints, so that any subscriber in the district, irrespective of the exchange to which he pertains, has a centralised service at his disposal.

(o) As has already been explained, the transfer of toll traffic from one district switchboard to another is possible in order to utilise the services of the operating personnel to the fullest extent.

(p) Other fundamental features of the T.E.T.I. system are as follows:

(q) The called subscriber must have facility for freeing himself from a connection.

(r) It must be possible to send ringing current through an engaged train of switches without breaking down the connection, so that in the case of a toll call, ringing may be repeated freely at the discretion of the operator.

(s) The system must operate satisfactorily over a subscriber's loop with a maximum resistance of 800 ohms, including the subscriber set. The minimum insulation resistance of the subscriber lines and junctions may fall to between 10,000 to 20,000 ohms, measured between the two wires of the line, and between each wire and earth, without endangering the satisfactory operation of the system.

(t) The number of permissible faults in each automatic exchange must not exceed 5 per 1,000 for every 5,000 calls sent in.

(u) The automatic exchange equipment must be housed in iron or glass casings for protection purposes.

Conclusion

The installation projected by the Società Tirrena aims at the constitution of a complete network of automatic switching centres in Tuscany with nineteen manual switchboards for routing the calls between districts and registration of calls on a fee basis. The same principles have also been adopted in the conversion of the Liguria and Lazio areas.

Voice Frequency Dialling

Field Trial and Demonstration in Italy of Four Frequency Toll Signalling System

An interesting demonstration of voice frequency dialling was given at Rome on October 30th, 1929, when dialling into the Florence automatic area 280 Km. away was carried out from a number of subscribers' sets in Rome, and also from an operator's position at Rome. The new four frequency toll signalling system developed by the International Telephone and Telegraph Laboratories was used, and the demonstration was attended by the following officials:

His Excellency Admiral Ciano, Minister of Communication in the Fascist Government; Professor Commandante Pession, Director General of Posts and Telegraphs; Professor Di Pirro, Technical Director of Posts and Telegraphs; Commandante Delpino, Director General of the Società Telefonica Tirrena; Engineer Zanni, Technical Director of the Società Telefonica Tirrena.

The trial was carried out in conjunction with the Società Telefonica Tirrena, who are the concessionaires of the Fourth Zone. A special set-up was arranged by means of which the normal subscriber's set of each of the above officials was used to dial directly not only the subscribers of Florence but also those of Livorno, Siena, Empoli, Pontedera, Pistoia and other centres of Tuscany (using the Società Telefonica Tirrena's "celere" switching system). As no difficulties were experienced, either during the actual demonstration or during the preliminary trials, the demonstration may be regarded as a very satisfactory test of the possibility of dialling by means of the four frequency system.

In the regular course of operation the equipment in question provides for service from an operator's position and for automatic calling and clearing signals and for supervision by the Rome operator of the called subscriber in Florence. The transmission of impulses by means of voice frequency equipment has, of course, been carried out in the past, but this installation is believed to be the first voice frequency dialling equipment designed to give complete signalling facilities that has been set up in Europe on a commercial basis.

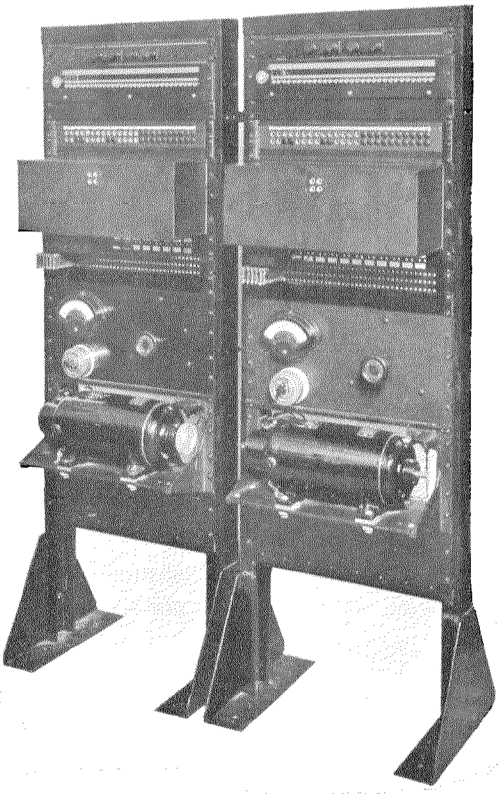


Figure 1—Equipment Used for the Rome-Florence Demonstration of Voice Frequency Dialling.

The four frequency system which has been used is a new voice frequency system, the outstanding feature of which is that it uses signalling currents of four frequency within the voice range. The large number of different frequency combinations obtainable afford a greater degree of flexibility in the matter of producing complex supervisory signals.

Further, the use of signals consisting of more than one frequency makes it easy to avoid false

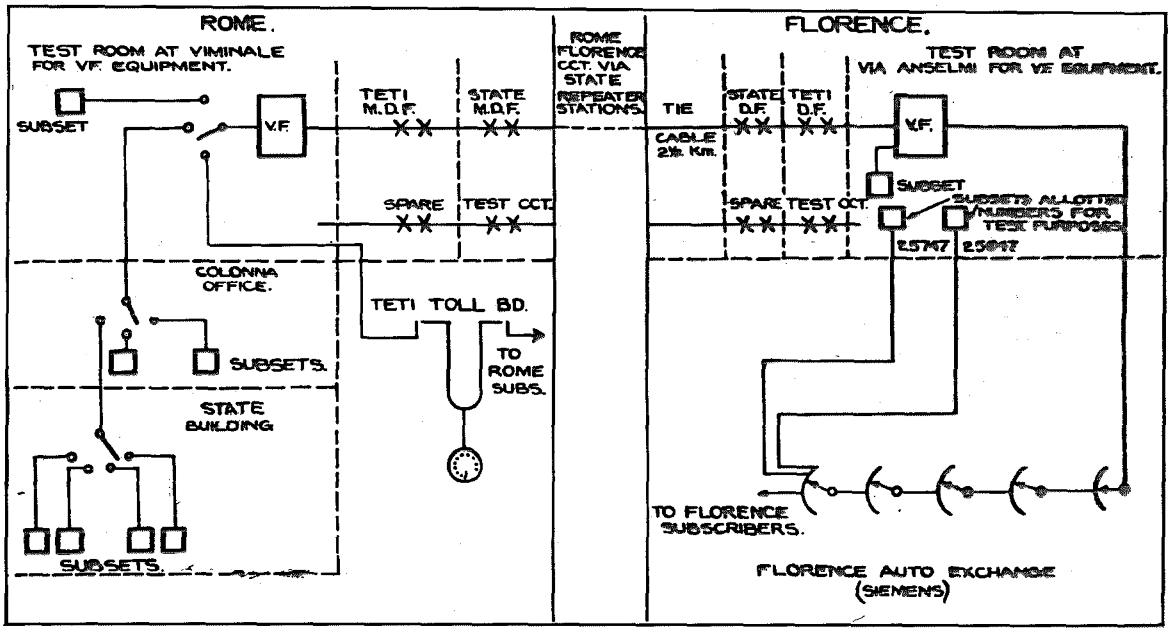


Figure 2—Circuit Layout of Field Demonstration and Trial in Italy of the Four Frequency Toll Dialling System.

operation of the signalling circuits by voice currents. This is one of the outstanding difficulties of automatic working on toll lines by voice frequency methods, and the four frequency solution, by providing in a single step both adequate and flexible signalling facilities and freedom from voice operation, may be considered an important advance in technical methods. In this system tuned voice frequency relays of a simple design are used to detect the voice frequency currents, and only a 24-volt battery is required. The system has been developed as part of a general study which is being made by the International Telephone and Telegraph Laboratories with a view to the provision of more efficient toll switching systems.

The accompanying reproduction (Figure 1) shows the equipment which was used for the Rome-Florence demonstration. One of the small racks shown was installed at Florence and the other at Rome. Each rack carries a voice frequency generator with its control circuits, together with a small panel which mounts the line equipment, and which is seen near the top of the rack. This line equipment consists of a group of voice frequency relays and direct current relays. As an instance of the reliability of the voice frequency relays it may be recorded that after a very severe journey from London, which actually smashed some of the screw heads holding the panels to the racks, and damaged all the direct current relays, it was still unnecessary to adjust the voice frequency relays or even to take off their covers.

The circuit layout of the trial and demonstration is shown in Figure 2. A standard two-wire medium heavy loaded circuit was used, this being one of the circuits in the new Rome-Florence cable installed by the Società Italiana Reti Telefoniche Interurbane, and opened on October 28th, 1929. Normally the line terminated at an operator's position, but it could also be switched through to a number of Rome subscribers' sets, so that a particular Rome subscriber could be made, in effect, a Florence subscriber.

The method of working used by the toll operator was as follows. To obtain a subscriber in the Florence district she plugged her cord into the line, and, without waiting, dialled the desired number. On receipt of the Florence subscriber's reply the operator's supervisory lamp was extinguished. When the Florence subscriber hung up, the supervisory lamp was lit again, and the operator then pulled out her plug and the circuit was restored to normal. It will be seen that the toll operator was thus able to treat the toll line in the same way as she treats a local junction leading to local automatic equipment.

When the Florence subscriber was busy the operator received a busy tone. The voice frequency circuits were arranged to provide the toll operator with facilities for offering the call to the busy subscriber and to provide busy flash, but the automatic equipment for Florence did not permit this, and consequently these facilities were not used. For a permanent installation under these conditions the equipment would be so arranged as to permit the Rome operator to call a special B operator at Florence, who would carry out the toll offering and toll breakdown. In a permanent installation, also, both way working would probably be used, so that a Florence operator could also pick up the line and dial a Rome subscriber, at the same time making the line busy to the Rome operator.

It should be mentioned that this particular application of the four frequency toll signalling system is only one of several possible and it is not necessarily suited to all conditions. The four frequency system is able to provide code impulses (using different combinations of the four frequencies for each digit) so that a Rome operator could set up a register in Florence by means of a key set instead of a dial. Such an arrangement enables the operator to carry more traffic and reduces her errors, and is therefore to be preferred to the dialling system.

Power Plant for Unattended Automatic Telephone Exchanges

By E. WOLLNER

IN view of the increase in the number of automatic exchanges, and especially of small rural exchanges, it has become necessary, for economic reasons, to adopt means for reducing the supervisory staffs. The machine switching part of the exchange is now so highly perfected that it will operate satisfactorily without constant supervision. A further step is to apply to the power plant of the exchange automatic controlling devices whereby the whole can be left without attendance during certain time intervals. As the number of available trained personnel is rather limited and as their salaries constitute an appreciable part of the maintenance charges, the advantages that accrue from avoiding the necessity for continuous supervision of the exchange are obvious.

The present account is concerned with automatic regulation of machines and automatic charging of the exchange batteries. The problem is not new; in fact, several solutions have been proposed.

The systems introduced with a view to automatic control of the power plant equipment may be divided into two classes. To the first of these classes belong systems developed for the purpose of regulating the working of the machine and of the switches from some distant point. Current impulses, sent over special wires, are used to govern the operation of power switches, circuit breakers, etc., in the distant power stations. A system of this type entails rather intricate apparatus, and initial cost is rather high compared with the cost of the telephone power plant. For this reason remote control is considered to be uneconomical for the purpose mentioned.

A solution to the problem was sought in the second class of system—the application of local control to power plants. The basic principle here is not to interfere with the working of the power plant from an outside point, but to leave the control to a few voltage and current operated instruments located in the power room itself. These instruments are so constructed and adjusted that the voltage of the battery is automatically kept to a predetermined value and the charging machine is automatically started or stopped according to the condition of the battery.

The various functions of a local control system for power plants are carried out by the following apparatus:

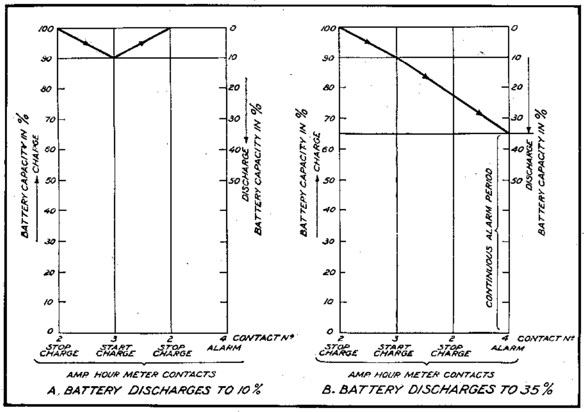
(a) A relay designed in the form of a voltmeter, the pointer of which stands in the rest position between two contacts, the left one of which will be touched by the pointer when the voltage drops below a certain value and the right one when the voltage rises above a certain predetermined value. As the contacts are adjustable, the control circuits, which are closed by the pointer, can be properly adjusted.

(b) An ampere hour meter, consisting of a simple form of mercury motor provided with four sets of contacts.

The first contact (No. 1) acts simply as an earth connection; the remaining three contacts designated, respectively, "No. 2 Stop charge," "No. 3 Start charge," and "No. 4 Alarm" are wiped over by a mobile arm. Contact No. 3 is fixed at a point corresponding to 10% of the total battery discharge (Figure 1-A). The fourth and last contact is intended to close an alarm circuit to the Main Exchange, at a point corresponding to 35% of the total battery discharge, when, during the travel of the arm over contact No. 3, the charging set does not start up (Figure 1-B). The alarm segment on the meter extends from the 35% discharge point to the full discharge point, and thus gives a prolonged alarm.

(c) A set of relays, the working of which is governed by the apparatus mentioned under (a) and (b), which in turn operate a motor-driven rotary switch and a level switch.

In the following, an application of the local control system will be described for the case of a power plant which consists of a storage battery having 25 cells, and of a charging set composed of a three-phase A.C. motor directly coupled to a D.C. charging generator. In order to keep the voltage at the bus-bars as close to 48 volts as possible, use is made of 7 C.E.M.F. cells connected in series with the main battery. By an automatically driven switch, the individual C.E.M.F. cells are cut in or cut out according to the prevailing voltage condition. A D.C. motor provided for the drive of the rotary C.E.M.F. cell switch is constructed in such a way that it can rotate in either direction. The fundamental charging circuit is shown by heavy lines in Figure 2. The auxiliary circuits by which the automatic regulation of voltage and the starting or stopping of the charging set is effected are indicated by thin lines.



A. BATTERY DISCHARGES TO 10%

B. BATTERY DISCHARGES TO 35%

Figure 1—Battery Control Points—Power Plant for Unattended Automatic Exchanges.

The operation of most of the relays in the auxiliary circuits is governed by the voltmeter-relay or by the ampere hour meter. The voltmeter-relay is connected across the buss-bars. The ampere hour meter is placed in the lead between the charging machine and the main battery.

The relays are grouped according to their various functions. One set is for raising or lowering the battery voltage (see relays marked "low" and "high" in Figure 2), another set for starting and stopping the machine (see sets marked "start" and "stop").

The voltmeter relay and the ampere hour meter with its associated relays provide for automatic control of the power plant, which, therefore, can be left totally unattended, though —as will be explained later—means are also provided for manual operation if that becomes necessary.

Let us now imagine a power plant of the type just described to be put into service, and let us observe how the automatic regulation is accomplished, when the battery is in use, considering each of the more important operations separately:

Voltage of Battery Drops Below 48 Volts

When the bus-bar voltage drops more than two volts below 48 volts, the contact needle of the voltmeter relay makes contact *A*. This closes the circuit of relay R_4 which operates and establishes another circuit over its right-hand contact. In the last mentioned circuit,

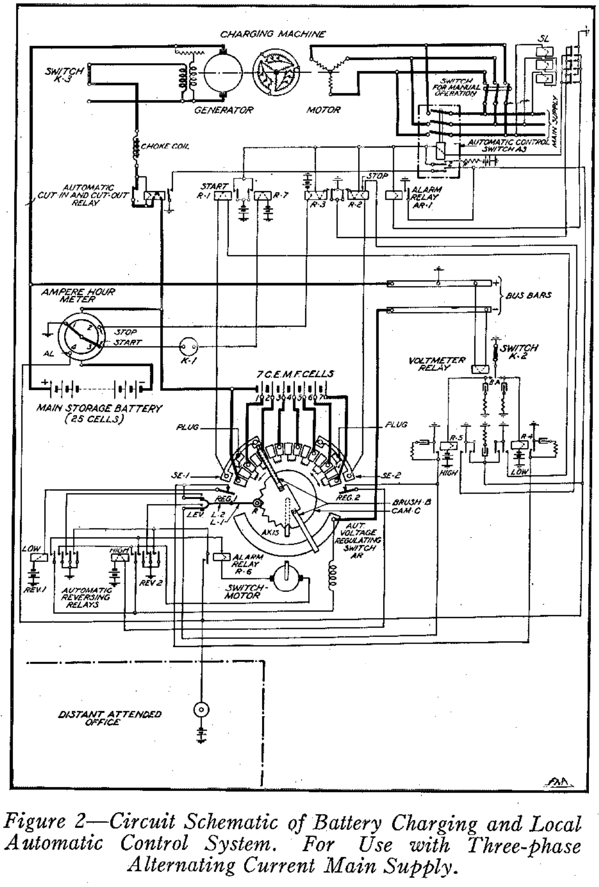


Figure 2—Circuit Schematic of Battery Charging and Local Automatic Control System. For Use with Three-phase Alternating Current Main Supply.

the reversing relay REV_1 responds and closes by its first and second armatures the circuit of the switch motor. The automatic voltage regulating switch AR, which is of the radial pattern, therefore rotates in counter-clockwise direction, indicated in Figure 2 by a single arrow. On the axis of the motor is fixed a cam C to which are attached the brushes B of the regulating switch. During the rotation of the switch AR one of the brushes B slides over a large semi-circular contact, while the other brush B passes over a number of small metal segments. The large segment is connected to the negative bus-bar and each of the smaller ones to one of the C.E.M.F. cells. As soon as cam C commences to rotate in counter-clockwise direction, the toothed part of the cam lowers a lever arm L_1 to which a slide roller R is fastened. Correspondingly, the left-hand lever arm L_2 is raised, and the switch LEV at the end of the left lever arm becomes closed. From that time, the REV_1 relay is fed over the lever switch contact LEV and over the regulating switch contact REG_1, so that the motor continues to rotate until brush B completes the step commenced, and centres on the next segment of the voltage regulating switch, in this way cutting out one of the C.E.M.F. cells. (To simplify the circuit-drawing, individual batteries are indicated in the auxiliary circuit; it is, however, to be understood that no special batteries are required for the operation of the relays, and that the necessary current is drawn from the bus-bars.)

If the increase of 2 volts is sufficient to re-establish the voltage of 48 volts on the bus-bars, the pointer of the voltmeter relay returns to its middle position, releasing relay R_4. At the end of the step, the roller R will fall in the hollow between two teeth of cam C causing the opening of contact LEV. The circuit of REV_1 relay is now broken; this causes the opening of the circuit of the switch motor. Brush B will centre and stop on a contact corresponding to the cutting out of one C.E.M.F. cell. If the increase of voltage is insufficient, the voltmeter relay needle will remain on the contact A. The broken upper contact of switch LEV has no effect on the operation of the regulating switch, since relay R_4 is still operated, and REV_1 relay therefore continues to attract its armature, which means that the brush B will continue for another step.

Voltage of Battery Rises Above 48 Volts

When the voltage on the bus-bars is increased by 2 volts above the normal battery voltage, the needle of the voltmeter relay will close contact B, establishing the circuit of relay R_5, which operates and closes another circuit by its left-hand contact. In this last circuit, relay REV_2 operates; this, in its turn, closes the circuit of the series motor with the result that brush B will now rotate in a clockwise direction as indicated by a double arrow in Figure 2. The method of stepping of the brush B is the same as described above. Each step of the brush will introduce one C.E.M.F. cell in series with the main battery until the bus-bar voltage is automatically restored to its normal value.

Automatic Starting of the Charging Machine

There are two means provided for the automatic starting of the charging machine. In one case the starting depends on the battery voltage condition, i.e., on the voltage at the bus-bars associated with the position of the automatic voltage regulating switch AR. In the other case the switching in of the machine is a consequence of the capacity condition of the battery.

Now consider more closely the first mentioned case and, for the sake of illustration, assume that it is required that the charging of the battery should commence when the brush B is on the segment corresponding to the first C.E.M.F. cell. To insure the starting of the machine at the proper moment, a plug will have to be inserted between a sector SE_1 and a segment S_1, both of which are placed concentrically to the segments on the switch AR. It will be noted from Figure 2, that as soon as brush B arrives at the segment which is connected to the 1st C.E.M.F. cell, the extension of brush B touches the segment S_1 and that then a circuit is closed by relay R_1. This circuit can be traced from a left-hand contact of relay R_4 which has been operated via contact A of the voltmeter relay. When relay R_1 attracts its armature, another circuit is closed, which contains the operating coil of the automatic control switch *AS*. The switch *AS* connects the main supply circuit to the charging motor and causes it to start.

In the second means provided for the starting of the charging motor, the charging set can also be controlled by the operation of the ampere hour meter. If the battery is discharged to, say, 90% of its capacity (*i.e.*, 10% discharge), the ampere hour meter will close its contact No. 3. When contact No. 3 closes, a new circuit is established in which relay R_7 will be operated. The last named relay in its turn closes another circuit, which energises the operating coil of switch *AS*, and the charging motor starts in the manner previously described. The operating coil of switch *AS* is maintained active by a holding circuit which can be traced in Figure 2, from resistance *R*, to contact *Z* of *AS* and to the front contact of relay R_2.

As soon as the generator voltage is sufficiently high, the automatic cut-in and cut-out relay closes the circuit for battery charging, and if the bus-bar voltage is raised to 48 volts, contact *A* of the voltmeter relay will be opened. This, however, has no other effect, as the control switch *AS* remains operated over the holding circuit of its coil.

Automatically Disconnecting the Charging Machine

When the predetermined number of C.E.M.F. cells are introduced in series with the battery, and when the further charging of the battery is unnecessary, the machine may be stopped automatically, provided that the ampere hour meter has closed its contact No. 2, thus indicating a complete charge. When it is desired that 6 C.E.M.F. cells shall be in service to indicate the completion of the charge as regards voltage, a plug is inserted between sector SE_2 and segment S_2. When the brush arrives at the position where it touches segment S_2, a circuit will be closed by the relay R_2, which energises and locks over its front contact. Relay R_2 will remain operated until its locking circuit is opened by the subsequent operation of relay R_3 when the ampere hour meter closes its contact No. 2.

As the charging progresses, contact No. 2 will be closed when the ampere hour meter indicates the completion of the charge. At the moment that contact No. 2 is closed, relay R_3 is operated and breaks at its back contact the connection with the positive pole of the battery. This means that the locking circuit of the operating coil of switch AS is interrupted. It releases and opens the motor circuit. The charging set is thus disconnected and, in slowing down the generator current through the coil of the automatic cut-in and cut-out switch will be reduced to zero. This switch releases also, disconnecting the generator from the main battery.

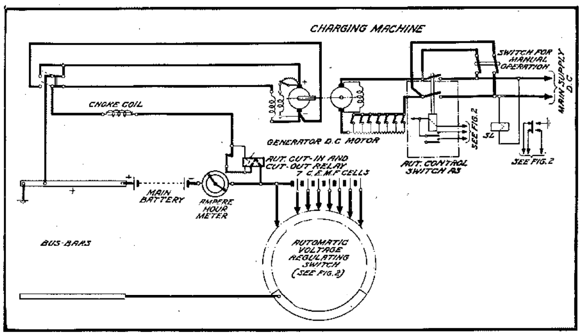


Figure 3—Circuit Schematic of Battery Charging and Local Automatic Control System. For Use with Direct Current Main Supply.

As soon as the generator has been disconnected from the battery, the voltage of the individual accumulator cells will decrease from 2.7 volts to about 2.15 volts. Thus, the voltage at the bus-bar will gradually decrease below 48 volts. When this happens, it will be necessary to cut out the 6 C.E.M.F. cells progressively, one at a time, *i.e.*, the cells placed in service during the charge, as above described. Each time the bus-bar voltage drops below 48 volts, the contact *A* of the voltmeter relay will be closed. In consequence of this, relay R_4 will be energised, causing the rotation of the automatic voltage regulating switch AR in a counter-clockwise direction, which then cuts out the C.E.M.F. cells, one at a time.

Control of Main Supply Circuit

In Figure 2 a charging circuit is indicated with a three-phase alternating current main supply circuit. The power plant control system just described can also be applied where direct current is furnished from the local power mains. In this case a few changes are necessary in the fundamental battery charging circuit, as indicated in Figure 3.

Whatever the type of supply current available, there is provision to prevent unexpected occurrences in the main supply circuit interfering with the satisfactory working of the charging machine. Special relays are provided to disconnect the operating coil of the automatic control switch *AS* every time the main supply circuit is disturbed. If alternating current is used, then for every condition a separate supervisory relay *SL* is employed (see Figure 2), whereas in the case of D.C. supply, one such relay (see Figure 3) is sufficient. When, owing to some outside trouble, one of the *SL* relays releases its armature, then the locking circuit of the *AS* coil will be opened, and the automatic control switch will disconnect the motor from the main supply circuit.

Supervisory and Alarm Circuits

To insure the satisfactory operation of the power plant, and to avoid damage to the vital part of the equipment owing to unexpected troubles, a few special circuits are provided.

To limit the movement of the rotary switch *AR* use is made of the contacts REG_1 and REG_2. If, for instance, the switch *AR* continues its counter-clockwise rotation after having cut out all the C.E.M.F. cells, the brush B will butt against and open the contact REG_1, so that any subsequent closure of the voltmeter relay contact *A* will have no effect on the switch motor. Under these conditions, the closure of contact *A* will operate relays R_4 and R_1 and will thus start the charging set, as previously described.

Similarly, the contact REG_2, at the right-hand side of the switch *AR* limits the clockwise rotation of this switch, when the maximum number of C.E.M.F. cells has been put into the circuit, thus preventing the switch from moving beyond the last position. The method of stopping the switch motor is analogous to that described in connection with the counter clockwise rotation.

Precautions are also taken to anticipate the occurrence of irregularities in the working of the power plant, in which case warning signals are sent to the distant attended Main Exchange. The corresponding alarm circuit consists of a signal wire between the exchanges, and also of a bell and a battery connected as in Figure 2. An automatic alarm signal will be sent to the attended exchange in each of the following cases:

(1) When one of the supervisory relays SL releases its armature. If *SL* fails to operate whilst switch *AS* has closed its contacts, the alarm relay AR_1 will attract its armature and an alarm will be given indicating power failure during the charging operation.

(2) When the right-hand contact of the automatic cut-in and cut-out switch closes at the same time that the remote control switch AS is operated. In this case the alarm indicates that the automatic cut-in and cut-out switch is not operating while the charging machine is running.

(3) When the reversing relays (REV_1 or REV_2) are operated, but alarm relay R_6 is at rest. This alarm indicates that the circuit for the switch motor is closed, but that its armature circuit is open, thus preventing the motor from rotating.

(4) When the voltmeter relay operates to close either its *A* or *B* contacts. Normally, these contacts should only be closed intermittently for short intervals until the conditions causing the voltmeter needle to leave its centre position are corrected. This intermittent closing happens in cases of low or high voltage as previously described. Short, intermittent alarm signals, therefore, indicate normal operation, but a continuous alarm would mean that the condition is abnormal and requires attention.

(5) When—owing to defective operation of the charging set—the alarm contact on the ampere hour meter closes, the alarm in this case is continuous.

(6) When one of the fuses (not shown in the circuit) of the charging or discharging circuit blows.

Manual Operation

It may sometimes be required to operate the power plant manually instead of automatically. This is made possible by temporarily disabling the automatic operation, and by putting into service the equipment for manual handling. When, for instance, during overcharge, manual operation is required, then switches K_1 and K_2 are opened. These switches temporarily disable the local contacts of the ampere hour meter and of the voltmeter relay, which means that automatic control is discontinued.

In addition to the above, a switch is introduced into the generator circuit (see switch K_3

in Figure 2) to change the connections from counter compound for automatic operation to a regular shunt connection for hand operation. Further, a switch is provided in the motor circuit to connect the power supply, independently of the automatic control switch *AS*. The hand operation of the complete circuit works in the well-known manner.

Conclusion

In developing an automatically controlled power plant for unattended telephone exchanges, it has been the aim to solve the problem without intricate apparatus. The practical application of the system described has proved that it covers all essential requirements without excessive first cost or maintenance charges.

Figure 4, which shows the front equipment of a power board installed in the automatic telephone exchange at Jerez (Spain), indicates the more important apparatus described in this paper.

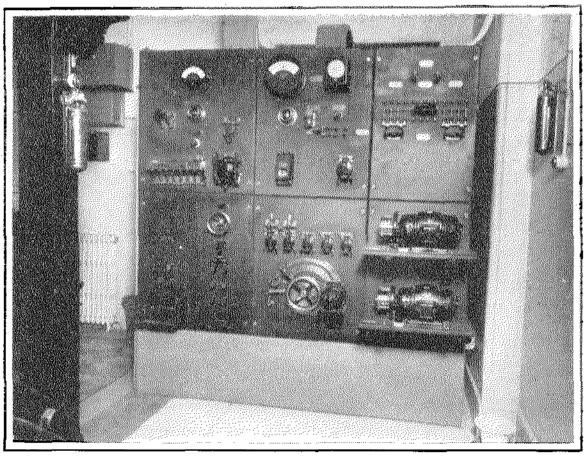


Figure 4—Front Equipment of Power Board. Automatic Telephone Exchange, Jerez, Spain.

An Electrical Frequency Analyzer*

By MASATSUGU KOBAYASHI, *Kogakushi*

Engineering Department, Nippon Electric Co., Tokyo

FOR the detailed study of sounds, of electromagnetic induction in communication lines by power circuits or composite electrical waves comprising various frequencies, etc., it is often necessary to separate and measure the constituent frequencies. For this purpose the so-called electrical frequency analyzer may be conveniently used. By the use of the electrical frequency analyzer it is possible to analyze and record not only so-called higher harmonic waves but also any waves which comprise a number of different frequencies. With a harmonic analyzer which is used to analyze wave forms from their oscillograms some inconvenience is experienced when wave forms other than harmonics are comprised in a wave form to be analyzed. The various methods which have been employed heretofore for analyzing frequencies electrically utilize the selectivity of an electrical tuning circuit[1], the longitudinal resonance of an iron bar,[2] or a low path wave filter having an extremely low cut-off frequency.[3]

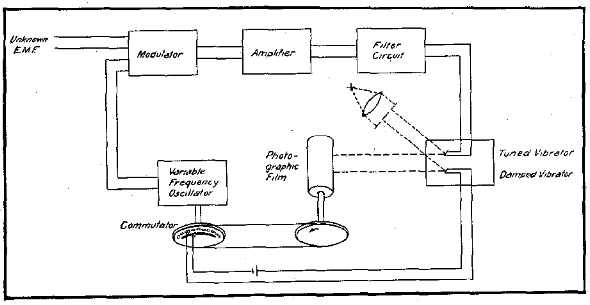


Figure 1—Schematic Drawing of the Frequency Analyzer.

The writer has recently conducted experiments with a design of electrical frequency analyzer which would appear to possess advantages not found in any other or previous types. It is the purpose of this paper to describe the theoretical considerations involved in its design, as well as the practical application of these principles, and to show some examples of the result obtained through the use of this interesting and, we believe, novel development.

1. *Outline of the Analyzer*

Figure 1 is a schematic drawing of the device. The variable frequency oscillator used with this analyzer is capable of generating currents varying in frequency from 7,530 to 14,530 cycles per second. This variation is produced by rotating the dial shown in the drawing through 180 degrees. The output from this variable frequency oscillator passes out to a modulator where it is modulated by the wave to be analyzed. If the frequency of the current to be modulated is F and that of the higher harmonic to be analyzed is f, three currents of frequencies F, F+f and F−f, respectively, are produced by modulation, as is well known. These currents, after being amplified by an amplifier and passing through a tuning circuit, flow into the vibrator shown in the drawing. The vibrator consists essentially of two conductors, mounted with a small mirror and stretched across a magnetic field. Light emanating from a special lamp is reflected from this mirror and projected upon a photographic film mounted upon a rotatable drum.

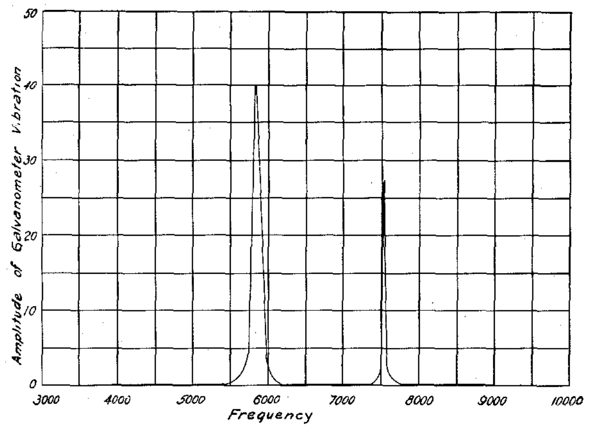


Figure 2—Relation Between the Frequency and Amplitude of Oscillation of Tuned Vibrator.

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[1] R. L. Wegel and C. R. Moore, *Bell System Technical Journal*, April, 1924, pp. 299-323.

[2] C. R. Moore and A. S. Curtis, *Bell System Technical Journal*, April, 1927, pp. 217-229.

[3] M. Grützmacher, Zs f. *Techn. Phys.*, Aug., 1927, pp. 506-509.

*Presented before World Engineering Congress, Tokyo, Section 6, October 31, 1929.

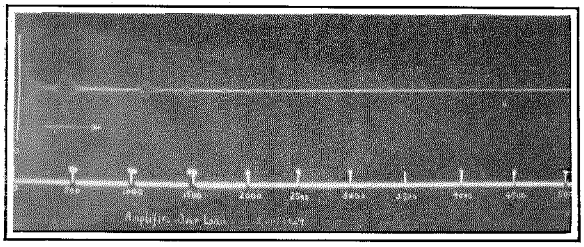

Figure 3—Harmonic Production of Overloaded Amplifier.

The vibrator has, usually, two tuning frequencies, as shown in Figure 2. Hence, if the resonance frequency of the tuning circuit is tuned to one of the tuning frequencies, say 7,530 cycles per second, the oscillation of the vibrator becomes marked only for this frequency. Now, if the frequency F is so varied that one of the frequencies F±f, say F−f, becomes 7,530 cycles per second, the vibrator starts its oscillation. Since the oscillation of the vibrator is proportional to the magnitude of the modulating current, it is proportional to the magnitude of the higher harmonic of frequency f. Therefore, if F is given a value ranging from 7,530 to 14,530 cycles, a current having a frequency ranging from 0 to 7,000 cycles per second may be analyzed. As the tuning characteristic of the vibrator is sharp, as shown in Figure 2, fairly accurate measurement can be made.

Now, the light oscillating in accordance with the oscillation of the mirror is projected upon a drum, as shown in Figure 1. Since the drum is wrapped with a light sensitive film, the latter is affected in a degree corresponding to the amplitude of the oscillation. If, as shown in the drawing, the drum and the dial of the variable frequency oscillator are so coupled that the drum makes one complete revolution when the dial is turned 180 degrees, the former makes one complete turn when the frequency of the current from the variable frequency oscillator is changed over the range of 7,530 to 14,530 cycles per second, corresponding to the 180 degrees turn of the dial. Since large oscillations are produced in the vibrator only when F−f equals its resonance frequency, a series of oscillations as photographed in Figure 3 is produced as the drum is turned. In this figure it is seen that harmonics or component frequencies are arranged in the order of their frequencies and corresponding to their magnitudes.

The angular displacement of the drum desig-

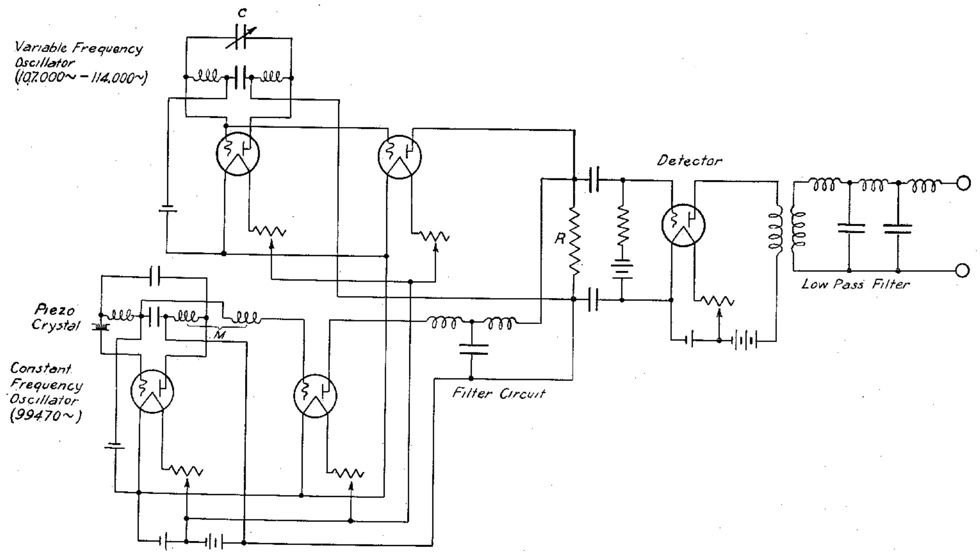
C
Variable Frequency Oscillator (107,000~ - 114,000~)
Detector
R
Low Pass Filter
Piezo Crystal
M
Constant Frequency Oscillator (99470~)
Filter Circuit

Figure 4—Beat Frequency Oscillator. (Frequency Range from 7530 Cycle to 14530 Cycle.)

nates a change in the frequency of the current output from the oscillator as was mentioned above. Hence, if contacts are provided for the dial, as shown in Figure 1, to indicate frequencies corresponding to dial positions, one of such contacts being provided at, say, every 1,000 cycles per second, so that the brush attached to the dial sweeps over these contacts, a scale graduated in frequencies, as shown in Figure 3, to correspond to the displacement of the drum, may be obtained. Arrangement may be made as shown in the figure to supply current to other vibrators through these contacts.

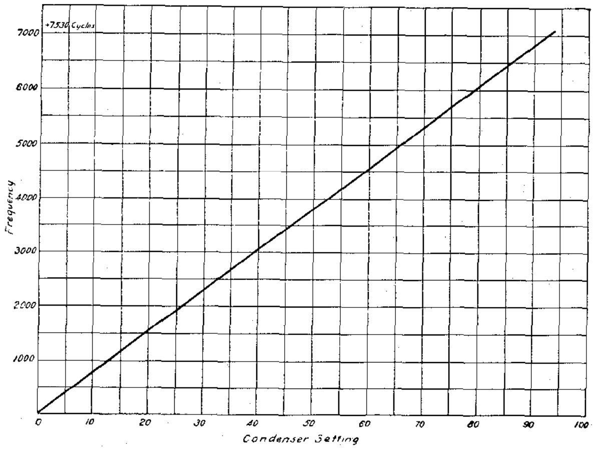

Figure 5—Frequency Characteristic of Beat Oscillator Corresponding to the Dial Setting of the Condenser.

2. *Double Frequency Oscillator*

It is necessary to keep the output of the oscillator constant throughout the frequency 7,530 to 14,530 cycles per second, produced by turning the dial through its complete range. This is accomplished by utilizing the beat of two currents as shown in Figure 4. For this purpose two oscillators may be employed, one of constant frequency and the other of variable frequency. Since stability is required of the constant frequency oscillator, a piezo oscillator capable of producing oscillations of 99,470 cycles per second is used. For the variable oscillator an ordinary valve oscillator, as shown in the figure, is used. If the condenser C is turned 180 degrees, it generates oscillations over the range of 107,000 to 114,000 cycles per second.

After the oscillatory currents from the constant frequency oscillator and the variable frequency oscillator are amplified respectively, and higher harmonics are eliminated from them by filters, these oscillatory currents are superposed through a resistance R to produce a beat. The terminal voltage of this resistance R is impressed on the grid of the next valve and is detected. Hence, if a transformer is connected to the output side and if the voltage is impressed on a low path filter, a beat frequency may be produced. For this purpose a filter having 50,000 cycles for the cut-off frequency may be used. Figure 5 shows the variation in frequency with changes in condenser degrees. It is seen that the rise in frequency is approximately proportional to the increase in the condenser setting, and the output current is almost constant over the frequency range required.

3. *Analyzing Circuit*

Figure 6 is the analyzing circuit employing grid modulation. If the waves to be analyzed are applied to circuit I and those to be superposed to circuit II, and if the secondaries of I and II are connected in series with the grid of the modulating valve, the latter waves are modulated by the former waves. The waves thus modulated are then amplified, and applied through a tuning circuit to the vibrator. Since in this analyzer a vibrator having very low

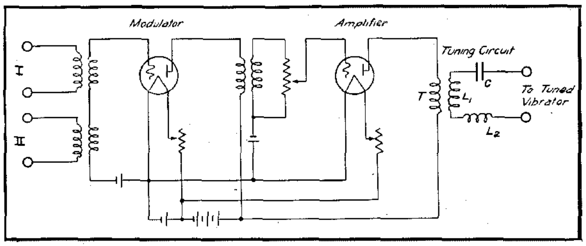

Figure 6—Analyzing Circuit Using Grid Modulation.

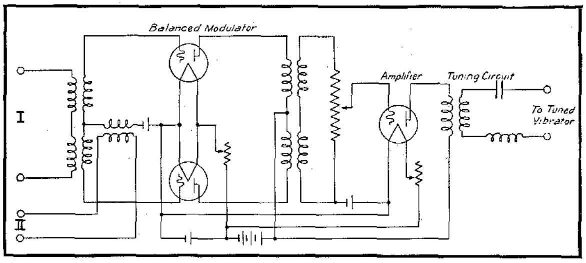

Figure 7—Analyzing Circuit Using Balanced Modulator.

resistance is used as described later under "Tuned Vibrator," a high step-down ratio of transformation is selected for the transformer T. If a tuning circuit is established with L_1, L_2, and C, the current which flows in this circuit is mainly of frequency $f_o = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$, currents of other frequencies being largely suppressed. If f_o is tuned to one of the resonance frequencies of the tuner, the tuner vibrates only for f_o, and consequently analysis can be made with this circuit.

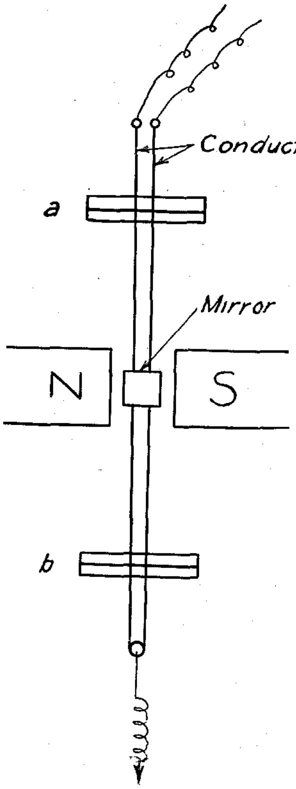

Figure 8—Schematic Drawing of Tuned Vibrator.

According to this method, which depends on grid modulation, frequencies F and F±f are produced and the vibrator oscillates, even when f=O, as shown in Figure 3. Though some inconvenience is introduced in this method for the analysis in the neighborhood of zero cycles, this inconvenience is avoided, if a balanced modulator shown in Figure 7 is used and the carrier is suppressed.

4. *Tuned Vibrator*

The tuned vibrator consists of two conductors stretched across a magnetic field as indicated in Figure 8, the conductors being subjected to considerable tension between blocks a and b. At the mid-point between a and b is mounted a small mirror. The tuned vibrator is, therefore, of the same construction as the vibrator element of the Duddel oscillograph.

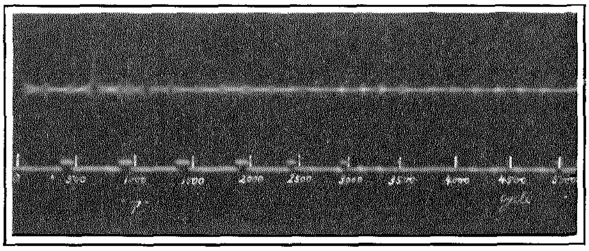

Figure 9—Vowel "a" short as in ah.

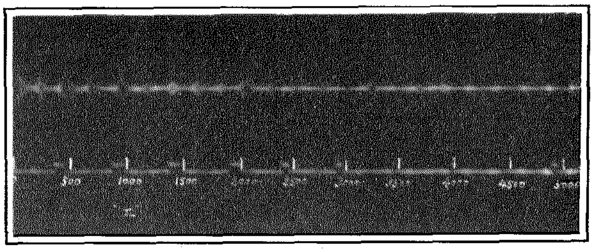

Figure 10—Vowel "a" long.

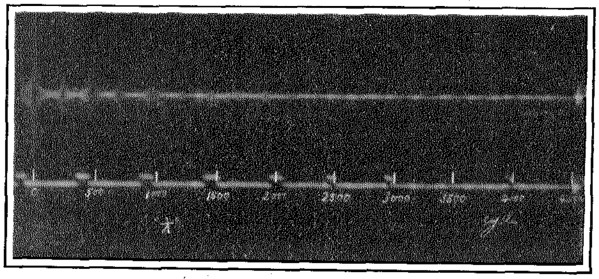

Figure 11—Vowel "o" long.

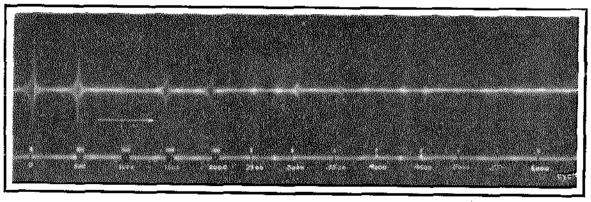

Figure 12—Harmonic Production When Alternating Current of 500 Cycle is Rectified by Two Electrode Vacuum Tubes

As is well known, the natural frequency of a stretched string is expressed by

$$f = \frac{1}{2}\sqrt{\frac{T}{lm}}$$

where T is the tension, l the length, and m the mass of the string. Now, if two conductors are connected in series as shown in the figure and a current is passed through these conductors, a certain angular displacement about the central axis is produced for the mirror. If the current passed is an alternating current the mirror vibrates about its central axis.

Since the stretched conductors have their natural frequency as mentioned above, if the frequency of the alternating current flowing through them coincides with this natural frequency, obviously the amplitude of the vibration becomes very large.

Figure 2 shows the variation in the amplitude of oscillation for varying frequencies when the current or the torsional force for the conductors is kept constant. From this it is seen that there are two resonance frequencies. This phenomenon has already been described* and is attributed to the difference in the natural frequencies of the two conductors. Since the existence of these two resonance frequencies introduces some inconvenience for the purpose of analysis, it is advisable to eliminate one of them. This is easily accomplished by the use of an electrical filtering device which is incorporated in the tuning circuit shown in Figure 6.

Since the sharpness in sensitivity depends on the friction of the moving part of the vibrator, it is not advisable to immerse the whole moving part in oil as in an ordinary oscillograph. It is thought that if the moving part is kept in a vacuum and the friction due to air is reduced, better results will be obtained.

5. *Examples of Application*

Using the frequency analyzer just described, the author has studied some electric and acoustic phenomena with rather interesting results. Since, however, the object of this paper is chiefly to describe the principle upon which the new analyzer is based, and a detailed description of all the various experiments and applications would be too long and beyond the scope of this paper, only a few examples of its practical application are shown herein.

Figure 3 is an example of harmonic production when too much voltage is impressed on the grid circuit of an amplifier. Figure 9 is "a" short as in ah. Figure 10 is "a" long and Figure 11 is "o" long. Figure 12 is an example of harmonic production when alternating current of 500 cycles is rectified by a two electrode vacuum tube.

In these examples, the carrier current is seen at the position of zero cycles, as grid modulation is used.

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*Aoki, Tada and Tomoda, *Journal of Japanese Inst. E. E.*, Oct., 1928, pp. 1065-1114.

The Determination of the Desirable Attenuation-Frequency Characteristic of a Long Toll Circuit

By A. R. A. RENDALL

International Standard Electric Corporation

SUMMARY. This article discusses the relative effects of phase and attenuation distortion on long toll cable circuits. It describes a series of tests made to show that the "tweet" noise introduced by phase distortion can be diminished by increasing the attenuation of the higher frequencies, without reducing the intelligibility of speech received over the circuit. The paper concludes by outlining certain cable plant studies which should be made before changes in loading systems are contemplated.

THE ideal overall attenuation-frequency characteristic of a long distance circuit has been a much discussed question in recent years. For some time it has been almost universal practice to equalise, to some extent, 4-wire circuits, especially medium heavy loaded circuits. The extent and method of equalising attenuation has varied from case to case, but it may be generally stated that the majority of Administrations have assumed that complete equalisation provides the ideal overall circuit characteristic.

In 1926 the C.C.I.[1] considered the question of the overall loss frequency characteristics of 4-wire and 2-wire circuits, and recommended that the circuits should be equalised within certain limits. According to the rule laid down, the overall circuits could be over equalised or under equalised.

In the application of the system designated 1A by the C.C.I. (*i.e.*, that adopted by the International Standard Electric Corporation), the practice has been always to under-equalise.

On 4-wire circuits, the one-way paths were fully equalised, and then 4-wire terminating sets were added, the transmission loss of which increased slightly with frequency. In the case of 2-wire circuits, the practice has been to employ 2-wire repeaters with flat or slightly rising gain characteristics, so that the overall loss of the circuit increased considerably towards the higher frequencies.

The recent tendency has been to narrow these limits within a defined frequency range, so that the overall characteristic more nearly approaches complete equalisation. At first sight this policy may appear to lead in the right direction, but it cannot be maintained that it is based on experimental evidence. The practice is therefore still open to challenge in the light of more definite knowledge.

The problem will first be examined theoretically and then the results of field trials will be recorded.

Consider, first, a one-way coil-loaded circuit, equipped with amplifiers whose pass range can be varied at will, and suppose that the repeater cut-off is progressively increased from a low value of frequency to one approaching the natural frequency of the circuit. If no other form of distortion were present, as each additional frequency band was added, the circuit intelligibility would increase. This intelligibility could be measured in terms of syllable or word articulation, or idea intelligibility. All these quantities are related as shown by John Collard (see C.C.I. Green Book—1928, Appendix 7, or *Electrical Communication*, January, 1929)[2], but great care must be taken in the use of these terms, when the quality of a circuit is expressed.

The telephone subscriber is really interested in idea intelligibility or "Time Efficiency" (as defined by Collard in the above references), and syllable articulation is a necessary step in the determination of the quality of a circuit. For example, a statement that the syllable articulation of a circuit is 70% may convey the wrong impression of the value of a circuit, but the equivalent "Idea Intelligibility" of 93% shows that the circuit is a good commercial circuit.

The effect of the frequency-band passed on the circuit articulation or intelligibility has been studied by several investigators, and the published results are supported by a large amount of experimental evidence. Figure 1 reproduces the syllable articulation cut-off frequency curve shown in Figure 136 of "Speech and Hearing" (Fletcher), and includes an idea intelligibility cut-off frequency curve for a high quality circuit. The latter curve was calculated from the former by the methods described by Collard in the article already mentioned. From these curves it will be observed that an increase in the circuit cut-off from 2,000 p.p.s. to 2,400 p.p.s. adds about 6% to the syllable articulation, and only 1% to the idea intelligibility.

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[1] Comité Consultatif International.

[2] A Theoretical Study of the Articulation and Intelligibility of a Telephone Circuit, *Electrical Communication*, January, 1929.

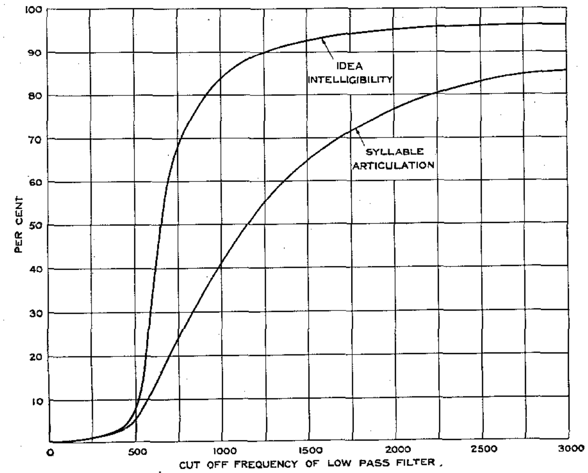

Figure 1—Idea Intelligibility and Syllable Articulation—Cut-off Frequency Curves.

(Reproduced by the kind permission of the publishers, D. Van Nostrand Company, Inc., New York, from Dr. Harvey Fletcher's book "Speech and Hearing.")

It may be objected that these curves, derived by the use of high quality apparatus, do not fairly represent the normal commercial case. The tests described later, show that similar conclusions apply for circuits using commercial subscribers' sets.

Returning to the consideration of the one-way circuit, as the circuit cut-off frequency is raised, and approaches the natural frequency of the loaded cable, another effect is introduced, that of transient distortion. It is well known that the higher frequency components of speech are propagated along a loaded cable at a much smaller velocity than the lower frequency components. The quantity which expresses the magnitude of transient distortion is $\frac{d\alpha}{d\omega}$, where the cable propagation constant is $P = \beta + j\alpha$, and $\omega = 2\pi x$ frequency. Figure 2 is a plot of this quantity, which may be regarded as time delay for a loading section of cable. It will be noted that the delay at 0.87 of the cable natural frequency is twice that at 0.2 of that frequency.

The high frequency components of speech will therefore arrive in incorrect time order, and this will affect the quality of received speech. On the shorter circuits the effects will not be noticeable; but as the circuit length is increased, a noise is introduced which can best be described as "tweet." This "tweet" is most noticeable after the more prominent consonants have been pronounced, and is due to the delayed high energy peaks arriving at a time when the speech energy is low. This noise interferes with speech, by distracting the listener's attention. When the circuit length is increased still further, blurring will result, and the syllables will become indistinct. This effect is similar to that produced by frequency distortion. In view of the disturbing effects of the higher frequencies due to transient distortion and to their small contribution to articulation, a

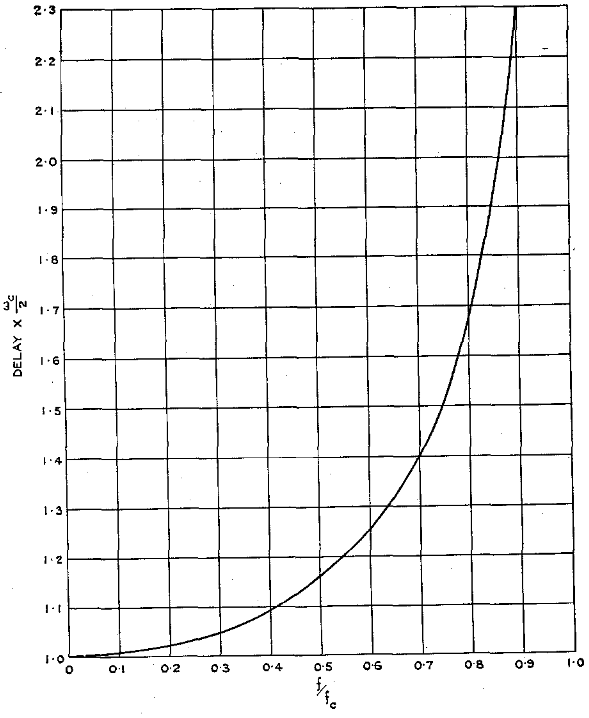

Figure 2—Delay Characteristic of Loaded Cable Circuit.

doubt can be reasonably expressed whether the presence of these frequencies at full volume is desirable.

It may be urged that the transient distortion should be limited, by raising the cut-off of the cable or introducing phase compensation. Either of these expedients would increase the circuit cost, and before such a course is taken it must be established that definite improvement is obtained, under working conditions, by transmitting these higher frequency components at full strength.

It therefore seemed necessary that field tests should be made to determine the desirable frequency range and attenuation characteristic of long circuits. Tests with this end in view were carried out by the International Standard Electric Corporation in France, Belgium, and Holland, by the kind permission of the Administrations concerned.

In 1927 preliminary tests were carried out on the Paris-Strasbourg cable, by the courtesy of the French Administration. A long medium heavy 4-wire circuit was set up and equipped with filters, so that a series of articulation tests could be made with different circuit cut-off frequencies. It was then observed that the detrimental effect of transient phenomena upon the utility of a telephone circuit could be divided into two distinct classes, as already noted. The total amount of syllable blurring caused by the limitation of the transmission band on one hand, and the transient phenomena on the other, when the circuit cut-off was varied from 1,800 to 2,400 p.p.s., did not vary appreciably. This was demonstrated in the articulation tests by the fact that a nearly constant percentage of syllables was correctly received for the various cut-off frequencies. The noise effect of the transients, however, increased most noticeably as the circuit cut-off was raised; but while its presence introduced a mental strain in listening to the syllables, it did not appreciably reduce the percentage of syllables correctly heard. From this it may be deduced that while the transient noise effect does not impair the reception of a syllable or word deliberately pronounced, it may distract the listener's attention so that he cannot group words into ideas so readily. It is quite clear that if two circuits exist, which give equal syllable articulation, the better circuit is the one with the smaller noise interference. At the tests made in Paris, numerous persons were asked to talk on the circuit, under different conditions of cut-off frequency, and all agreed that the circuit was better when the higher frequencies were attenuated.

The results of these tests indicated that a more complete field trial was desirable.

The opportunity arose in September, 1929, when the Belgian Administration kindly agreed to loan the circuits necessary for these trials.

The circuits actually set up are shown in Figures 3 and 4, and were in accordance with the C.C.I. system 1A. The cable constants were as follows:

Loading Coils	0.177 Henry
Loading Spacing	1,830 metres
Loading Section Capacity	0.070 mfd.
Cable Natural Frequency	2,850 p.p.s.
Conductor diameter	1.3 mm.

Figure 3 shows, diagramatically, the 2-wire side circuit, having a total length of 545.6 kms., and arranged with four 2-wire repeaters in tandem. A duplicate circuit of the same layout was set up for the purposes of direct comparison. Figure 4 shows the 4-wire side circuit, 864 kms. in length. Several weeks were spent in making articulation

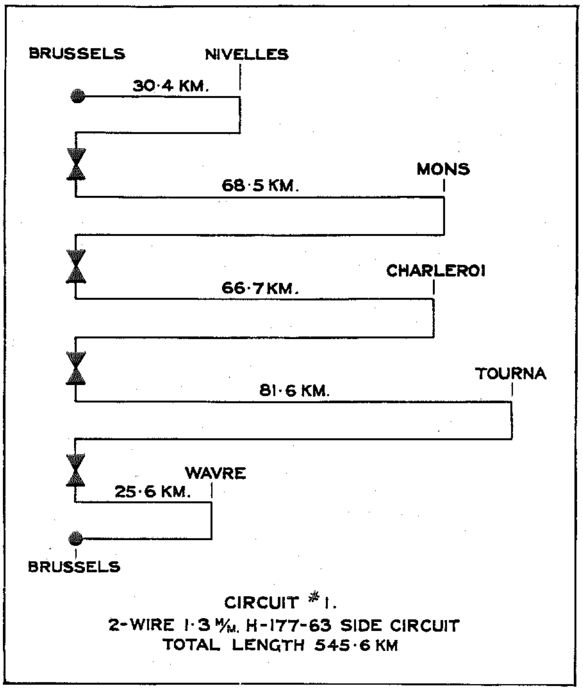

Figure 3—Experimental 2-Wire Circuit.

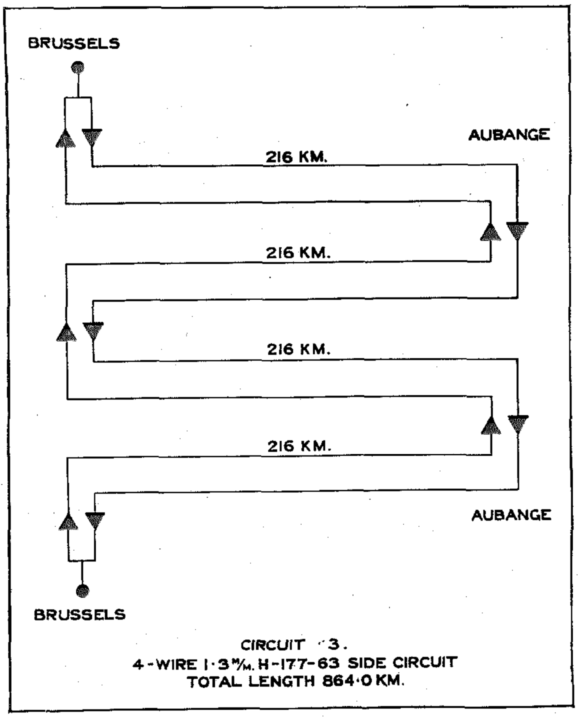

Figure 4—Experimental 4-Wire Circuit.

tests on these circuits, with various types of attenuation characteristics.

Before these tests are described in detail, it is necessary to explain the methods of making articulation tests which were adopted. Lists of specially selected words had been prepared, as the result of a careful examination of the English language. The frequency of occurrence of the sounds comprising spoken English had been determined, and these were incorporated into words of two or three sounds, so that a complete list of 80 words contained the sounds in proportion to their frequency of occurrence in the language. The words selected were ordinary English words, and therefore the results of the tests are in terms of "Word articulation." This method had been tried in the laboratory and had given excellent results. The expected accuracy of observation of word articulation, with the number of observations taken under each condition, was within ± 2%, although it is interesting to note that it was possible to repeat results with greater accuracy.

Three English observers made the articulation tests. Each man in turn pronounced a list of 80 words, and the other two men listened in parallel at the far end of the circuit, in two separate silence cabinets. In this way one complete set of tests produced six observations. In order that the circuit conditions should approach as nearly as possible to a normal subscriber-to-subscriber connection, commercial sub-sets were employed and connected to the line, through a network designed to simulate a 300 ohm subscriber's loop and standard cord circuit arrangements.

The first tests were made on the 2-wire circuit, Figure 3. The four intermediate 2-wire repeaters were located at Brussels, so that they were under the control of the observers. By changing the tuning circuit of these repeaters, different types of gain-frequency characteristics could be assigned to them. In this manner different overall attenuation-frequency characteristics could be obtained on the circuit. The three-circuit characteristics tested are shown in Figure 5. Curve A results from a rising repeater gain characteristic adjusted to equalise for the cable distortion. Up to 2,200 p.p.s., the equalisation is close, and the condition may be described as "fully equalised." At the two ends of the frequency scale, the repeaters "cut off." Curve B is the case where the intermediate repeaters had substantially flat gain-frequency characteristics over the frequency range 300–2,200 p.p.s., and consequently the rise in the cable attenuation, with frequency, was not compensated. Curve C corresponds to an intermediate case. For the three conditions, the net transmission equivalent at 1,000 p.p.s. was as near as possible 10 decibels. It should be realised that for circuit B the difference in attenuation between 1,000 and 2,200 p.p.s. is over 18 decibels.

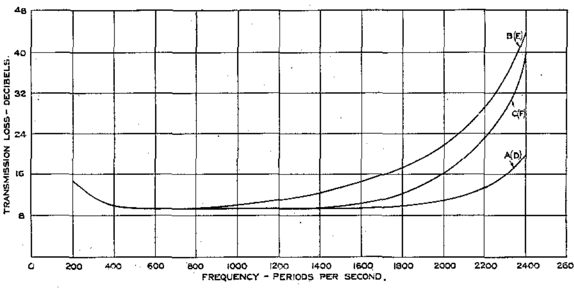

Figure 5—Loss Characteristics of Experimental 2-Wire Circuit.

Tests were first made with the circuit cut one-way, so that the effects of echo were eliminated, and then a second series of tests were made with the circuit cut two-way. The corresponding circuit conditions for the two-way case are described as D, E, and F.

A total of 12 sets of tests, or 72 observations (each observation means the pronunciation and writing down of 80 words), were made on condition A, and 66 observations on each of conditions B and C. The average results in word articulation were as follows:

Condition A—fully equalised........86.2%
Condition B—non-equalised.........86.2%
Condition C—partially equalised....88.4%

The tests were repeated for the circuit cut two-way. 36 observations were made on each condition, and the resulting word articulation was:

Condition D—fully equalised..........86%
Condition E—non-equalised...........86%
Condition F—partially equalised......88%

Although articulation testing methods are not sufficiently precise to enable much importance to be attached to the slight increase in articulation observed on conditions C and F, compared with A and D, yet in view of the corroboration evidence of tests described below, it can be stated that the word articulation for the non-equalised circuits is not less than that for the equalised circuits. This confirms the facts observed during the Paris tests, that the total syllable blurring, due to the effects of frequency and transient distortion, remains constant when the attenuation of the high frequency components is varied within the limits of the tests described.

The noise due to the transient distortion, however, was annoying for conditions A and D, and was absent for conditions B and E. On the partially equalised circuits, it was just noticeable. In order to establish this fact, a second 2-wire circuit was arranged, with length and layout the same as the first. This enabled a rapid change to be made from one condition to the other during a conversation. A number of persons were asked to converse over the circuit and to express their opinions. They were informed of the circuit condition by the naming of letter designations allocated to each circuit. Those who talked included three members of the Belgian Administration, five French-speaking, and three English-speaking members of the company.

It was unanimously agreed that a fully equalised circuit was the worst circuit to talk over because of the "tweet" due to transients. Little difference was observed between the partially and non-equalised conditions, but a slight lack of brilliance was noticed in the non-equalised case, although the voice was reproduced quite clearly.

Whether the circuit was cut one-way or both ways had no effect on the results. In the two-way condition an echo was observed by the talker, but its magnitude and time lag were not sufficient to cause any annoyance.

Similar tests were carried out on the medium heavy 4-wire side circuit, Figure 4. This circuit was 864 kms. in length, and as already stated, its constants were in accordance with C.C.I. system 1A, and therefore it was slightly in excess of the limiting length specified for this type of circuit.

The gain characteristics were adjusted to give different degrees of equalisation; and, when required, low pass filters were added to give the desired characteristic. Figure 6 shows the various overall attenuation-frequency characteristics which were tested for articulation.

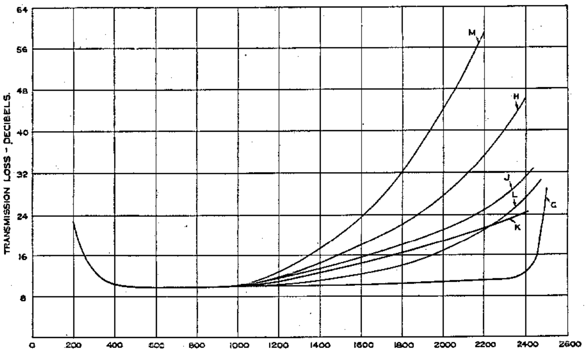

Figure 6—Loss Characteristics of Experimental 4-Wire Circuit.

The 1,000 cycle net equivalent in all cases was about 10 db. Curve G represents close equalisation up to 2,400 p.p.s., and the other curves give different degrees of distortion. Curve M represents an extreme case, which was taken to illustrate the great degree of distortion that can be tolerated, at the higher frequencies, before the "word articulation" is seriously affected. It should be realised in this particular case that the net loss at 2,200 p.p.s. is nearly 50 db. greater than the net loss at 1,000 p.p.s., and yet, from the figures below, it will be noticed that the articulation is only a few per cent lower than for the other cases.

The average percentage word articulation was as follows:

Condition	% Word Articulation
G (fully equalised)............	85
H (non-equalised)..............	83.5
J (partially equalised).........	84.5
K (partially equalised).........	87.0
L (partially equalised).........	86.5
M (extreme case of under-equalisation)............	82.3

These results confirm the previous conclusion, which may be restated generally as follows: If on a loaded cable circuit, the attenuation frequency curve is so varied that the higher frequencies are more efficiently transmitted, a point is reached where the increase in articulation obtained by an increment of high frequency energy is neutralised by the transient distortion caused by the increased frequency range passed.

The "tweet" heard on this circuit was more marked (in view of the greater length) than on the 2-wire circuit, and the quality of the speech was much improved by the attenuation of the higher frequencies. In order that the effects of transient distortion could be observed on a very long circuit, a one-way circuit of double the length (making a total length of 1,728 kms.) was set up, and this long circuit was equalised approximately. The articulation on the equalised circuit was 81%, and when attenuation was introduced at the higher frequencies, it was 85%. Here, definite improvement was obtained by under equalisation, and the "tweet" on the equalised circuit was so troublesome that continuous speech was nearly impossible. Conversation was quite reasonable on the circuit when the high frequencies were attenuated. These opinions were confirmed by numerous people who were asked to carry on a conversation over the circuits.

Further confirmation of these results was obtained by an abridged series of tests carried out at Eindhoven repeater station in Holland.

Reviewing the results of all tests the conclusion is arrived at that, unless phase compensation is employed, there is no advantage—in fact, a positive disadvantage—in fully equalising the attenuation to a high percentage of the cable natural frequency. The higher frequency components must be attenuated to an extent sufficient to reduce the "tweet" to a value where it is not objectionable. The tests indicate that if the loss at 2,200 p.p.s. is about 12 to 15 db. greater than at 1,000 p.p.s., this condition is satisfied. The question immediately arises whether this compromise has reduced the "word articulation" appreciably from the value which would have been obtained if the band of frequencies up to 2,200 p.p.s. had been passed with complete attenuation and phase equalisation. An answer to this question can be obtained by comparing, as given below, the best compromise articulation values of short and long circuits. On the shorter circuits the transient distortion is smaller, therefore it would be expected that the best compromise value would be higher.

Length	Best articulation value obtained
545.6 kms. (2-wire one way)..	88.4%
864 kms...................	87%
1,728 kms..................	85%

A further measure of the loss in articulation was obtained by a special test, in which the cable circuit was replaced by a distortionless artificial line of 10 db., the subscriber's loops being kept the same. The articulation value so obtained was 91%, therefore the loss from the absolute ideal, for commercial subscriber's apparatus, is as follows:

Circuit Length	Loss from ideal in "Word Articulation"	Loss from ideal in Idea Intelligibility
545.6 kms.	2.6%	0.5%
864.0	4.0%	1.0%
1,728.0	6.0%	1.5%

The gain in articulation which would be obtained with an actual circuit, in which the transient distortion was reduced by phase compensation or by an increase in the cable natural frequency, must therefore be very small for lengths of 864 kms., and still smaller for lengths of 545 kms. Before such expensive expedients are adopted, it would be well for all Administrations to answer the following questions:

What number of circuit kilometres fall into different categories of length—up to 100 kms., 100–200 kms., 200–300 kms. and so on?

How much would be gained in articulation, in each class of circuits, over the best "compromise" value, if transient distortion were reduced by raising the cable natural frequency or by using phase compensation?

How much would it cost in each class of circuits to reduce transient distortion in the manner described?

The determination of these factors, so that the systems finally recommended for the European toll cable network shall represent a true balance between quality and cost, constitutes a long and complicated problem, which needs the intensive coöperation of all concerned.

Whatever the outcome of such an investigation, experience already gained indicates that an economical grade of loading, such as the medium-heavy loading of systems Ia and Ib, without phase compensation, must inevitably play an important part in national and international circuits.

The author urges that consideration should be given to the conclusions reached in this article when deciding the practices governing the overall attenuation-frequency characteristics of toll circuits.

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INDEX TO VOLUME VIII

1929-1930

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AND TELEGRAPH CORPORATION
LIBRARY

ELECTRICAL COMMUNICATION

Volume VIII, 1929-1930

INDEX

Page

Aluminium Electrolytic Condenser, The, by *R. E. W. Maddison* .... October, 1929 109
Appleyard, Rollo: Pioneers of Electrical Communication—Claude Chappe—IX .... October, 1929 63
Automatic Telephony in the Zürich Area, by *E. Wollner* .... October, 1929 97
Billing, Ivar: Intercall Selector System on the Swedish State Railway .... July, 1929 16
Buttner, H. H.: The New York-Buenos Aires Radio Circuit .... April, 1930 259
Calculation of the Articulation of a Telephone Circuit from the Circuit Constants, by *John Collard* .... January, 1930 141
Caldwell, Fred T.: Inauguration of Madrid-Buenos Aires Radio Telephone Link .... February, 1930 249
Capek, A.: High Efficiency Multiple Magneto Boards .... October, 1929 89
Chappe, Claude (Pioneers of Electrical Communication—IX), by *Rollo Appleyard* .... October, 1929 63
Collard, John: Calculation of the Articulation of a Telephone Circuit from the Circuit Constants .... January, 1930 141
Control of Release Time of Relays in Automatic Telephone Systems, by *R. St. G. Terry* .... July, 1929 9
Craft, Edward Beech—In Memoriam .... October, 1929 108
Creed, F. G.: The Creed High Speed Morse Printing Telegraph System .... July, 1929 52
Creed High Speed Morse Printing Telegraph System, The, by *F. G. Creed* .... July, 1929 52
Czechoslovakian Cable System, by *F. J. Stringer*, *W. F. Marriage* and *E. L. E. Pawley* .... January, 1930 179
Dalzell, D. P.: A New Contribution to the Rational Design of Telephone Cables .... January, 1930 173
Deloraine, E. M.: The Use of Short Waves in Radio Communication February, 1930 213
Determination of the Desirable Attenuation-Frequency Characteristic of a Long Toll Circuit, The, by *A. R. A. Rendall* .... April, 1930 320
Development of Broadcasting in Japan, by *V. H. G. Parker* .... October, 1929 81
Electrical Communication in 1929 .... January, 1930 202
Electrical Frequency Analyzer, An, by *Masatsugu Kobayashi* .... April, 1930 315
Fairbank, N. K. and *Gray, G. H.:* Madrid-Buenos Aires Radio Link and Its Wire Connections .... February, 1930 208
Fairbank, N. K. and *Ullrich, E. H.:* Short Wave Directive Transmitting and Receiving Antennas .... February, 1930 235
Freeth, L. G.: The London-Paris-Madrid Telephone Service .... January, 1930 196
Fremery, de, F. and *Thomas, P. R.:* Terminal Equipments for Short Wave Point to Point Radio Links .... February, 1930 242
Gibson, W. T.: Thermionic Vacuum Tubes for Short Waves .... February, 1930 230
Gray, G. H. and *Fairbank, N. K.:* Madrid-Buenos Aires Radio Link and Its Wire Connections .... February, 1930 208
Gray, G. H.: The Unit of Transmission and the Transmission Reference System .... July, 1929 42
Gray, R. E. and *Ullrich, E. H.:* Short Wave Radio Telephone and Telegraph Receivers .... February, 1930 224

PAGE

Harper, E.: THE TRAINING OF LOCAL STAFF IN CEYLON FOR COMMUNICATION ENGINEERING WORKS .... January, 1930 164

Hatton, W.: A RURAL ROTARY AUTOMATIC TELEPHONE SYSTEM INSTALLED AT HERRLIBERG .... July, 1929 3

Herrera, Santiago Serra: PUBLIC ADDRESS SYSTEMS IN THE BARCELONA AND SEVILLE EXHIBITIONS .... January, 1930 135

HIGH EFFICIENCY MULTIPLE MAGNETO BOARDS, by *A. Capek* .... October, 1929 89

Hinton, L. T., Rendall, A. R. A. and *White, C. S.:* PHASE RELATIONS IN UNBALANCED TWO-WAY TELEPHONE REPEATERS .... July, 1929 34

INAUGURATION OF MADRID-BUENOS AIRES RADIO TELEPHONE LINK, by *Fred T. Caldwell* .... February, 1930 249

IN MEMORIAM—EDWARD BEECH CRAFT .... October, 1929 108

IN MEMORIAM—DR. M. MERKER .... January, 1930 139

INTERCALL SELECTOR SYSTEM ON THE SWEDISH STATE RAILWAY, by *Ivar Billing* .... July, 1929 16

INTRODUCTION TO SPECIAL ISSUE ON MADRID-BUENOS AIRES SHORT WAVE RADIO TELEPHONE LINK, by *G. H. Nash* .... February, 1930 207

Jillard, A. G.: THE MODERN PLANT OF THE NIPPON ELECTRIC COMPANY, LIMITED, AT TOKYO .... July, 1929 28

Kobayashi, Masatsugu: AN ELECTRICAL FREQUENCY ANALYZER .... April, 1930 315

Latimer, K. E.: METHODS OF LOCATING CROSSTALK FAULTS ON LOADED CABLES .... July, 1929 45

LIGHTNING DAMAGE TO TOLL CABLE .... January, 1930 194

LONDON-PARIS-MADRID TELEPHONE SERVICE, THE, by *L. G. Freeth* .... January, 1930 196

Maddison, R. E. W.: THE ALUMINIUM ELECTROLYTIC CONDENSER .... October, 1929 109

MADRID-BUENOS AIRES RADIO LINK AND ITS WIRE CONNECTIONS, by *G. H. Gray* and *N. K. Fairbank* .... February, 1930 208

Marriage, W. F., Stringer, F. J. and *Pawley, E. L. E.:* CZECHOSLOVAKIAN CABLE SYSTEM .... January, 1930 179

MERKER, DR. M.—IN MEMORIAM .... January, 1930 139

METHODS OF LOCATING CROSSTALK FAULTS ON LOADED CABLES, by *K. E. Latimer* .... July, 1929 45

MODERN PLANT OF THE NIPPON ELECTRIC COMPANY, LIMITED, AT TOKYO, THE, by *A. G. Jillard* .... July, 1929 28

Nash, G. H.: INTRODUCTION TO SPECIAL ISSUE ON MADRID-BUENOS AIRES SHORT WAVE RADIO TELEPHONE LINK .... February, 1930 207

NEW CONTRIBUTION TO THE RATIONAL DESIGN OF TELEPHONE CABLES, A, by *D. P. Dalzell* .... January, 1930 173

NEW YORK-BUENOS AIRES RADIO CIRCUIT, THE, by *H. H. Buttner* .... April, 1930 259

Niwa, Yasujiro: A SYSTEM OF ELECTRICAL TRANSMISSION OF PICTURES April, 1930 283

Parker, V. H. G.: DEVELOPMENT OF BROADCASTING IN JAPAN .... October, 1929 81

Pawley, E. L. E., Stringer, F. J. and *Marriage, W. F.:* CZECHOSLOVAKIAN CABLE SYSTEM .... January, 1930 179

PHASE RELATIONS IN UNBALANCED TWO-WAY TELEPHONE REPEATERS, by *L. T. Hinton, A. R. A. Rendall* and *C. S. White* .... July, 1929 34

PIONEERS OF ELECTRICAL COMMUNICATION, CLAUDE CHAPPE—IX, by *Rollo Appleyard* .... October, 1929 63

Pocock, L. C.: PROGRESS IN SUBSCRIBERS' TRANSMISSION APPARATUS April, 1930 265

Pocock, L. C.: THE "SOLID BACK" CARBON BUTTON TELEPHONE TRANSMITTER .... July, 1929 49

POWER PLANT FOR UNATTENDED AUTOMATIC TELEPHONE EXCHANGES, by *E. Wollner* .... April, 1930 309

PROGRESS IN SUBSCRIBERS' TRANSMISSION APPARATUS, by *L. C. Pocock* April, 1930 265

PUBLIC ADDRESS SYSTEMS IN THE BARCELONA AND SEVILLE EXHIBITIONS, by *Santiago Herrera Serra* .... January, 1930 135

RAPID TOLL, SUBURBAN AND RURAL AUTOMATIC TELEPHONE SERVICES IN TUSCANY, by *L. A. Zanni* .... April, 1930 296

Reinoehl, R. M.: SALESMANSHIP IN TELEPHONE DEVELOPMENT .... July, 1929 25

Rendall, A. R. A.: THE DETERMINATION OF THE DESIRABLE ATTENUATION-FREQUENCY CHARACTERISTIC OF A LONG TOLL CIRCUIT .... April, 1930 320

Rendall, A. R. A., Hinton, L. T. and *White, C. S.:* PHASE RELATIONS IN UNBALANCED TWO-WAY TELEPHONE REPEATERS .... July, 1929 34

		PAGE
RURAL ROTARY AUTOMATIC TELEPHONE SYSTEM INSTALLED AT HERRLIBERG, A, by *W. Hatton*	July, 1929	3
SALESMANSHIP IN TELEPHONE DEVELOPMENT, by *R. M. Reinoehl*	July, 1929	25
Sanborn, J. W.: TYPE D-1 SINGLE CHANNEL SHORT HAUL CARRIER TELEPHONE SYSTEM	October, 1929	122
SHORT WAVE DIRECTIVE TRANSMITTING AND RECEIVING ANTENNAS, by *E. H. Ullrich* and *N. K. Fairbank*	February, 1930	235
SHORT WAVE RADIO TELEPHONE AND TELEGRAPH RECEIVERS, by *E. H. Ullrich* and *R. E. Gray*	February, 1930	224
"SOLID BACK" CARBON BUTTON TELEPHONE TRANSMITTER, THE, by *L. C. Pocock*	July, 1929	49
"STANDARD" SHORT WAVE RADIO TRANSMITTERS, THE, by *C. E. Strong*	February, 1930	216
Stringer, F. J., Marriage, W. F. and *Pawley, E. L. E.:* CZECHOSLOVAKIAN CABLE SYSTEM	January, 1930	179
Strong, C. E.: THE "STANDARD" SHORT WAVE RADIO TRANSMITTERS	February, 1930	216
SYSTEM OF ELECTRICAL TRANSMISSION OF PICTURES, A, by *Yasujiro Niwa*	April, 1930	283
TELEPHONE AND TELEGRAPH STATISTICS OF THE WORLD	October, 1929	128
TERMINAL EQUIPMENTS FOR SHORT WAVE POINT TO POINT RADIO LINKS, by *F. de Fremery* and *P. R. Thomas*	February, 1930	242
Terry, R. St. G.: CONTROL OF RELEASE TIME OF RELAYS IN AUTOMATIC TELEPHONE SYSTEMS	July, 1929	9
THERMIONIC VACUUM TUBES FOR SHORT WAVES, by *W. T. Gibson*	February, 1930	230
Thomas, P. R. and *de Fremery, F.:* TERMINAL EQUIPMENTS FOR SHORT WAVE POINT TO POINT RADIO LINKS	February, 1930	242
TRAINING OF LOCAL STAFF IN CEYLON FOR COMMUNICATION ENGINEERING WORKS, THE, by *E. Harper*	January, 1930	164
TYPE D-1 SINGLE CHANNEL SHORT HAUL CARRIER TELEPHONE SYSTEM, by *J. W. Sanborn*	October, 1929	122
Ullrich, E. H. and *Fairbank, N. K.:* SHORT WAVE DIRECTIVE TRANSMITTING AND RECEIVING ANTENNAS	February, 1930	235
Ullrich, E. H. and *Gray, R. E.:* SHORT WAVE RADIO TELEPHONE AND TELEGRAPH RECEIVERS	February, 1930	224
UNIT OF TRANSMISSION AND THE TRANSMISSION REFERENCE SYSTEM, THE, by *G. H. Gray*	July, 1929	42
USE OF SHORT WAVES IN RADIO COMMUNICATION, THE, by *E. M. Deloraine*	February, 1930	213
VOICE FREQUENCY DIALLING: FIELD TRIAL AND DEMONSTRATION IN ITALY OF FOUR FREQUENCY TOLL SIGNALLING SYSTEM	April, 1930	306
White, C. S., Hinton, L. T. and *Rendall, A. R. A.:* PHASE RELATIONS IN UNBALANCED TWO-WAY TELEPHONE REPEATERS	July, 1929	34
Wollner, E.: AUTOMATIC TELEPHONY IN THE ZÜRICH AREA	October, 1929	97
Wollner, E.: POWER PLANT FOR UNATTENDED AUTOMATIC TELEPHONE EXCHANGES	April, 1930	309
Zanni, L. A.: RAPID TOLL, SUBURBAN AND RURAL AUTOMATIC TELEPHONE SERVICES IN TUSCANY	April, 1930	296

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